Volume 30 April 28, 1955 Number 3

# BULLETIN

OF THE

## AMERICAN PHYSICAL SOCIETY

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PROGRAMME OF THE

## 1955 WASHINGTON MEETING

AT

WASHINGTON, D. C.

April 28, 29, and 30, 1955

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# BULLETIN

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April 28, 1955 Vol. 30, No. 3

# BULLETIN

OF THE

# AMERICAN PHYSICAL SOCIETY

## 1955 WASHINGTON MEETING, APRIL 28, 29, and 30, 1955

THE **1955 Spring Meeting** of the American Physical Society will be held in Washington, D. C., on Thursday, Friday, and Saturday, **April 28, 29, and 30, 1955.** There will be changes from the system of the last few years. This year, most of our scientific sessions will be held in halls of the Sheraton Park Hotel (for the last time it is explained that this is the former Wardman Park Hotel). In addition, we shall use the East Building Lecture Room of the National Bureau of Standards for one session on each half-day, and the great Lisner Auditorium of George Washington University for the Fermi Memorial Symposium (see below). There is also a new Chairman of the Local Committee, R. D. Huntoon of the National Bureau of Standards. Hugh Odishaw, who at his request has been relieved of this heavy chore after several years of exemplary service, has been so kind as to lend his aid, and the new Chairman is no doubt being assisted by many others who shall be named in the Minutes of this meeting. Even so, it must be a very considerable task for him, and our gratitude should be fervently expressed.

**Hotel.** A considerable number of rooms have been set aside for our members in the Sheraton Park Hotel. If you have not already made your room reservation, write direct to the hotel, not failing to mention that you are a member of this Society. Should the quota of rooms be filled, the hotel will get you accommodations elsewhere.

**The registration desk** will be located in the Sheraton Park Hotel. Members and guests are asked to register and to **pay the modest registration fee** of one dollar. Adjacent to the desk will be blackboards on which will be written the names of post-deadline papers (if any), notices of messages for members, and changes in assignment of sessions to halls if such should become needful. Look at it often.

The memory of **Enrico Fermi will be honored in a half-day Symposium** to be held on Friday morning in the largest available hall. This Symposium has been arranged by our Past President, H. A. Bethe, who has invited F. Seitz, E. Konopinski, E. Segrè, W. H. Zinn, and H. L. Anderson to recount various aspects of the enormous achievement of our great and lamented friend and former President, not necessarily excluding work which followed as a consequence of his. President Cloyd H. Marvin of George Washington University has very graciously granted us free use of the immense and excellent Lisner Auditorium for this important session. Ask at the registration desk how best to go thither.

**Invited papers** are to be more numerous at this meeting than they were a year ago. Apart from the memorial Symposium mentioned just above, we shall have eleven in or near to nuclear physics (by E. Ambler, K. M. Crowe, E. G. Fuller, A. Ghiorso, D. J. Hughes, H. V. Neher, G. T. Reynolds, L. I. Schiff, M. M. Shapiro, A. W. Sunyar, and R. L. Walker); two in thermodynamics (V. K. LaMer and F. G. Brickwedde); two in cryogenics (R. P. Feynman and A. L. Schawlow); seven in solid-state and other fields of physics (L. M. Branscomb, F. Herman, G. T. Rado, W. W. Scanlon, N. Sclar, L. V. Spencer, and W. W. Tyler); and the **Symposium of our Division of Chemical Physics** on Friday afternoon (Session Q).

Three hundred and ninety-four **ten-minute papers** are distributed among thirty-three sessions. This is fewer than last year by 12: the difference is slight but has helped to save us from 16-paper and even 17-paper sessions such as disconcerted last year's listeners. One would like to believe that the Washington meeting has passed its peak, but the experience of *The Physical Review* shows that what seems to be stabilization can be very transitory. The theoretical physicists (who will find themselves in the Caribar Room this year as last) will not like the distribution of their 75 papers into only five sessions, of 15 papers each; this was made so as to free them on the Friday morning for the Fermi

memorial. There is some ambiguity in the assignment of papers on proton-proton interactions between sessions N and Z, and some in the assignment of papers between the "transmutation" group and the "radioactive substances" group, and some between the former of these and the "neutron physics" group. Magnetic resonance of various types is masked under the title "Radio-Frequency Spectroscopy." Transmutation is booming, and so are semiconductors, despite the fact that they will have had so big a show at Baltimore. The Society owes a debt to W. W. Havens, Jr., A. Pais, and C. S. Wu for arranging the papers in the fields of their particular expertness.

The **banquet of the Society** will be held on Friday evening at seven in the Continental Room of the Sheraton Park Hotel. The after-dinner speakers will be R. W. G. Wyckoff and John von Neumann. The price of the dinner will be four dollars. Use the form on the inside back-cover page for advance reservation, and be reminded that you may include your check for the dinner with the registration fee, dispatching them both in advance to the Chairman of the Local Committee.

**Tea.** The staff of the National Bureau of Standards and the staff of the National Science Foundation will be our hosts at tea, which they will offer to the members and guests of the Society at the Manse (on the Bureau grounds) from 4:30 to 6:30 P.M. on Thursday.

**Ladies** will be favored with a **programme of entertainment** for which they will be indebted largely to Mrs. Lauriston S. Taylor of the Local Committee. On Friday there will be a luncheon at the Normandy Farms; transportation will be provided; those who will go must announce themselves at the special Ladies' Registration Desk in the Sheraton Park during Thursday. On Thursday afternoon there will be a tour. Ask at the Ladies' Registration Desk for details of this and other plans.

The **Nominating Committee** of the American Physical Society will meet on Friday at 4:30 P.M. in the Conference Room of the South Building of the National Bureau of Standards. This Committee consists of H. A. Bethe (*Chairman*), Harvey Brooks, S. A. Goudsmit, S. A. Korff, R. E. Marshak, Leona Marshall, W. A. Nierenberg, G. B. B. M. Sutherland, and L. S. Taylor.

The **Council** of the American Physical Society will meet on the Wednesday afternoon at 1:30 in the Conference Room of the South Building of the National Bureau of Standards, unless contrary notice is distributed to its members.

A **Book Exhibit** will be held in the Foyer to the Main Ballroom of the Sheraton Park Hotel, and everyone is invited to examine the latest physics and technical books. There will be no **Placement Register** at this meeting.

**Post-deadline ten-minute papers,** pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, April 22. The abstracts will not be printed. The titles of such papers as may be accepted will be written on a blackboard near the registration desk, and the papers will be given (under the ten-minute rule) at a special session in Exhibit Hall II on Friday afternoon beginning at 2:00.

**Prospective meetings and deadlines** of the Society are listed on pages 5 and 6 of this Bulletin, together with instructions for the preparation of abstracts.

The abstracts printed in this Bulletin will reappear, exactly as they here stand, in an issue of *The Physical Review* after the meeting. Errata will be printed on a following page of the *Review* if received not later than Monday, May 16, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstracts marked with corrections! Write out the corrections in the form "Instead of . . . read . . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

## Preliminary Announcement of the 1955 June Meeting at Toronto

The 1955 June meeting of the American Physical Society, its 1955 Summer Meeting in the East, will be held in Toronto, Ontario, on Wednesday, Thursday, and Friday, June 22, 23, and 24. (Note the days of the week! they are so chosen as to give our members the opportunity of wandering over Ontario during the weekend.) As usual, our Division of Electron Physics makes this June meeting its principal meeting of the year. Unique is the fact that this will be our first joint meeting with the Canadian Association of Physicists. The Association will have a meeting of its own, with sessions of invited papers, on the Monday and Tuesday immediately preceding ours (June 20–21). This will be open to our members, and a programme may be had on application to Professor B. W. Sargent, Queen's University, Kingston, Ontario, Canada.

The University of Toronto will accommodate in its residence halls or those of other colleges such of our members, men and women alike, as write for reservations to Professor G. D. Scott, University of Toronto, Toronto 5, Ontario, Canada. The rates will be three dollars per day per person in single or double rooms. The following hotels are listed with their rates for single and double rooms: King Edward, $6.85 up and $10.85 up; Park Plaza, $10 and $12; Windsor Arms, $7 and $9; Westminster, $7 and $12; Westmoreland, $6.50 and $11; Frontenac Arms, $6 and $10. The Royal York ($9 up and $12.30 up) has another convention and may have few rooms to spare for ours. Write direct to the hotel of your choice, saying that you are coming for our meeting. Early reservation is recommended; Ontario is resort country in June.

Abstracts of contributed ten-minute papers, prepared according to the usual regulations (see page 6), will be accepted from members of the Canadian Association of Physicists and from members of the American Physical Society, provided that they arrive not later than Friday, April fifteenth, at the address hereunder. Abstracts may be offered in English or in French, and will be printed in the Bulletin in the language in which they are submitted.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

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## Preliminary Announcement of the 1955 August Meeting in Mexico City

The 1955 August meeting of the American Physical Society, complementing the normal Summer Meeting in the East and supplanting the normal Summer Meeting in the West, will be held on Monday, Tuesday, and Wednesday, August 29, 30, and 31. This will be our first joint meeting with the Sociedad Mexicana de Física, and our first in the new buildings of the Universidad de México.

Hotel rooms are to be reserved by writing to Aguirre's Guest Tours, Luis Moya 5, México 1, D.F., Mexico. This should be done promptly, with mention of the Society and with statement of the dates of your arrival and departure.

Abstracts of contributed ten-minute papers, prepared according to the usual regulations (see page 6), will be accepted from members of the Sociedad Mexicana de Física and from members of the American Physical Society, provided that they arrive not later than Friday, June seventeenth, at the address hereunder. Abstracts may be offered in English or in Spanish. Those received in Spanish will be rendered into English and published in this language in our Bulletin. Those received in English will be rendered into Spanish and distributed in that language by the Sociedad Mexicana de Física. For this latter purpose our members are specially asked to send original and *two* carbon copies of each abstract—three copies altogether!—to the address below; the third copy will be forwarded to Mexico.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

**(Please keep this page on file!)**

## MEETINGS AND DEADLINES FOR THE REMAINDER OF THE SEASON 1954–1955

| *Place* | *Meeting dates* | *Deadline date* |
|---|---|---|
| Washington | April 28–30 | past |
| Toronto | June 22–24 | April 15 |
| Mexico City | August 29–31 | June 17 |

Abstracts of contributed papers for the foregoing meetings are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. To avoid danger of confusion, please do not send abstracts for any meeting until the deadline date of the previous meeting is past.

## RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

***By exception, three copies of each abstract are requested for the Mexico meeting, so that one may be furnished to our Mexican hosts for translation, see page 5 of this Bulletin.***

# EPITOME OF THE 1955 WASHINGTON MEETING

(Personal names are those of invited speakers. NBS stands for National Bureau of Standards; halls not so marked are in the Sheraton Park Hotel.)

## Thursday Morning

A. Cosmic rays. Main.
B. Neutron physics, I. Burgundy.
BA. Radio-frequency spectroscopy, I. Burgundy.
C. Metals. Exhibit II.
CA. Fission; Coulomb excitation. Continental.
D. Theoretical physics, I: meson theory and nuclear forces. Caribar.
DA. Scanlon, Sclar, Herman, Tyler. NBS, East.

## Thursday Afternoon

E. Walker, Crowe, Reynolds, Shapiro, Neher. Main.
F. Neutron physics, II; Hughes. Burgundy.
FA. Radiofrequency spectroscopy, II; optical and atmospheric physics. Exhibit I.
G. Semiconductors, I. NBS, East
GA. Ferroelectricity and ferromagnetism; Rado. Exhibit II.
H. Platt, Stearns, Sunyar, Schiff. Continental.
HA. Theoretical physics, II: mainly scattering theory. Caribar.

## Friday Morning

J. Fermi Memorial Session: Seitz, Konopinski, Segre, Zinn, Anderson. Lisner Auditorium, George Washington University.
K. Transmutation and nuclear energy levels, I. Burgundy.
KA. Fluid dynamics and general physics. Caribar.
L. Semiconductors, II. NBS, East.
LA. Chemical physics, Continental.
M. Branscomb, Spencer, Fuller, Ambler. Exhibit II.

## Friday Afternoon

N. Scattering and polarization of nuclei. Main.
P. Mostly hyperons and heavy mesons. Exhibit I.
PA. Transmutation and nuclear energy levels, II. Burgundy.
Q. Division of Chemical Physics: Prigogine, Kac; Business Meeting; Callen. Continental.
QA. Post-deadline papers, if any. Exhibit II.
R. Electron physics. NBS, East.
RA. Theoretical physics, III: mainly nuclear theory. Caribar.

## Friday Evening at 7:00

Banquet of the American Physical Society; Wyckoff, von Neumann. Sheraton Park, Continental Room.

## Saturday Morning

S. Mesons, I. Exhibit I.
T. Apparatus of nuclear physics, I. Main.
TA. Transmutation and nuclear energy levels, III. Burgundy.
U. Lamer, Brickwedde, Feynman, Schawlow. NBS, East.
UA. Various topics in solid-state physics. Exhibit II.
V. Radioactive substances, I. Continental.
VA. Theoretical physics, IV. Caribar.

## Saturday Afternoon

W. Apparatus of nuclear physics, II. Burgundy.
X. Ghiorso; various topics in nuclear physics. Main.
XA. Microwave and band spectra; Broida. Exhibit II.
Y. Cryogenics. NBS, East.
YA. Radioactive substances, II. Continental.
Z. Mesons, II. Exhibit I.
ZA. Theoretical physics, V; field theory. Caribar.

# PROGRAMME

## THURSDAY MORNING AT 10:00

## Main Ballroom

## (R. B. BRODE presiding)

### *Cosmic Rays*

**A1. Altitude Effect on Cosmic-Ray Fine Structure.** DANA T. WARREN,* *Colorado A & M College.*—Cosmic ray intensities have been measured at zenith-angle intervals of 2½° in the four principal geomagnetic azimuths at Fort Collins, Colorado. This is at the same magnetic latitude as Missouri, where fine structure was previously observed, but is at an altitude of 5000 instead of 1000 feet. The irregularity near the zenith, which is azimuthally unsymmetrical in Missouri, appears as a significantly low-zenith reading in all azimuths. However, the azimuthally symmetrical irregularities that are so marked in Missouri could not be found. The chi-test shows reasonably good agreement with parabolas (omitting the zenith reading), although the measurements covered both the same zenith-angle range and air-path range in which the effects were previously found. Combining residuals from the various azimuths shows no symmetrical irregularities greater than half the size of those in Missouri. Also, less accurate measurements in the north and south with 103 g/cm² of lead absorber shows one high point at 35°, probably not statistically significant. Thus the altitude effect confirms the difference previously deduced between these two kinds of fine structure.

* Now at the University of California Radiation Laboratory, Livermore, California.

**A2. Azimuthal Effect for Cosmic-Ray Protons and Alpha Particles Using a Cerenkov Counter.*** J. R. WINCKLER AND L. PETERSON, *University of Minnesota.*—Data has been obtained with a large Čerenkov telescope containing two five-inch diameter end-window photomultipliers. The work is an extension of earlier experiments.[1] These experiments consistently showed too small an azimuthal effect for agreement with the accepted spectrum of primary protons. Alpha particles, however, should undergo less atmospheric scattering and have a much closer directional correlation with primary nuclei following collisions. The telescope was flown at 11 g/cm² atmospheric depth at geomagnetic latitude 40° for six hours at a 60° zenith angle. The pulse-height distributions in each azimuthal sector are compared in an absolute sense with the distribution for relativistic particles (sea level mesons). Preliminary analysis of part of the data shows that a large fraction of the singly charged particles at 11 g/cm² are distributed in velocity below $\beta = 1$ and are of secondary origin. The results for the alpha component will be discussed and compared with the proton component and the alpha primary spectrum obtained in other ways.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. R. Winckler and K. Anderson, Phys. Rev. **93**, 596–605 (1954).

**A3. Latitude Effect on the Nucleon and Hard Components of Cosmic Rays.** D. C. ROSE AND J. KATZMAN, *National Research Council, Canada.*—During the summer of 1954 cosmic-ray measurements were taken aboard the Canadian Navy Icebreaker Labrador during a cruise through the Northwest Passage and circumnavigating the North American Continent. The apparatus consisted of a neutron monitor or pile of lead and paraffin with $BF_3^{10}$ neutron counters and a triple coincidence Geiger-counter telescope with five niches of lead shielding. The results show that for the nucleon component the knee in the latitude effect is at about 54° north geomagnetic latitude. The results for the hard or mesonic component are complicated by difficulties in temperature correction but show the latitude knee to be somewhat higher in latitude than previous measurements.

**A4. Variation of the Position of the Cosmic-Ray Neutron Intensity Maximum with Geomagnetic Latitude.*** R. K. SOBERMAN, A. BEISER, AND S. A. KORFF, *New York University.*—It has been experimentally demonstrated that there exists a maximum in the cosmic-ray neutron intensity when plotted as a function of altitude or pressure. The position of this maximum at various geomagnetic latitudes in the northern hemisphere has been measured by experiments which used balloon borne unshielded $BF_3$ counters with various enrichments of the $B^{10}$ isotope. It has been found that the position of the maximum varies approximately parabolically when plotted as a function of geomagnetic latitude. The range of variation is from about 120 millibars at the equator to about 70 millibars at the north geomagnetic pole. The experimental results will be compared with theory.

* Supported by the Office of Naval Research.

**A5. Geomagnetic Albedo at Rocket Altitudes at the Equator.** H. GRIEM AND S. F. SINGER, *University of Maryland.*—Cosmic-ray secondaries above the "top" of the atmosphere ("albedo") present an unknown contribution in experiments designed to measure the flux of primary protons. The question of albedo is of particular importance at the geomagnetic equator; it enters into all considerations connected with the primary spectrum, in particular the energy balance. At the present time our knowledge of the equatorial albedo is sparse: it is >35 percent of the total flux at 45° zenith angle and made up mainly of minimum ionizing particles.[1] In attacking the albedo problem theoretically, we note that at the equator the magnetic field confines charged secondaries to the altitude region in which they are produced. Depending on altitude and range they can make many loops between production and absorption, thus enhancing their contribution to the counting rate. This process has been studied in detail for protons and electrons of various energies, and their relative contribution to the albedo is discussed.

[1] S. F. Singer, Phys. Rev. **80**, 47 (1950).

**A6. Changes in the Low-Energy Primary Spectrum and the Low-Energy Particle Cutoff of Cosmic Radiations.** PETER MEYER AND J. A. SIMPSON, *The University of Chicago.*—The solar magnetic dipole field can no longer be invoked to account for the low-energy particle cutoff in the primary spectrum. Neutron detectors in high-altitude aircraft were used to measure changes in the cut-off particle rigidity and total intensity in 1948, 1951, and 1954. It was observed between 1948 and 1951 that the cut-off rigidity decreased to permit particles not present in the 1948 spectrum to reach the earth. Furthermore, the total primary particle intensity was observed to increase in such a way as to increase the exponent of the assumed power law spectrum at low-particle rigidities. There is evidence that the phenomenon is not of terrestrial

origin. Forbush has recently shown that the cosmic-ray intensity increased by ionization chambers has increased between 1947 and 1950, and that this change appears to be associated with the cycle of solar activity. If both changes are due to the same process then the low-energy particle cutoff is a property of the solar system.

**A7. Energy Spectrum of Medium and Heavy Primaries at $\lambda = 61°$.*** J. E. NAUGLE, P. S. FREIER, AND E. P. NEY, *University of Minnesota.*—A stack of 83 emulsions was flown at a geomagnetic latitude of 61° (Saskatoon, Canada) for the purpose of detecting and stopping medium- and heavy-primary nuclei. The stack was kept at an altitude of $10.8 \pm 0.6$ grams/cm² for 7.15 hours. The stack was flown upside down during ascent so that particles which stopped during ascent could be eliminated. The outside of the stack has been scanned for particles with $I/I$ min $\geqslant 25$ as measured by delta rays. Particles with $I/I$ min $\geqslant 30$ and with a possible range in the stack of $\geqslant 19.6$ grams/cm² of emulsion are being followed until they interact, leave the stack, or end; 210 particles have been followed, of which 85 have ended in the stack. The charge of the ending particles is being measured by delta-ray densities *vs* range and by a densitometer measurement of the width and opacity of the end of the track. The two methods agree to within about $\pm 0.5$ unit of $Z$. A preliminary energy spectrum in the region from 180 to 620 Mev/nucleon will be presented. The charge distribution in the same energy interval will also be presented.

* Supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research and by a grant from the Graduate School of the University of Minnesota.

**A8. High-Energy Nucleonic Component in the Atmosphere.*** L. ALTMAN, H. S. BRIDGE, AND R. W. WILLIAMS, *M.I.T.*—An experiment on high-energy cosmic-ray nucleons in the atmosphere has been performed at mountain altitudes using a large double ionization chamber which provides a measure of the energy of $\pi^0$ mesons created in nuclear interactions. The interactions considered were initiated by nucleons (or pions) in an energy range of 200 to 2000 Bev. Preliminary analysis yields the following: absorption mean free path in air (corrected for Gross transformation), approximately 105 g/cm²; integral frequency spectrum (deduced from the energy of $\pi^0$'s), $\sim E^{-1.5}$. There is an increasing degree of association between the nucleonic and electronic components of the cosmic radiation at the higher energies.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**A9. Rocket Observations on Soft Radiation at Northern Latitudes.*** F. B. MCDONALD, R. A. ELLIS, AND M. B. GOTTLIEB, *State University of Iowa.*—A combination Geiger counter and crystal scintillation counter telescope has been developed for rocket use to study the properties of a new soft radiation observed recently at high altitudes in northern latitudes.[1] The crystal (Na-I-Th activated) is mounted below a single thin-walled Geiger counter in the nose of the rocket. The Geiger counter gates the output of the photomultiplier so that the pulse height distribution of particles traversing the Geiger counter and entering the crystal is obtained. In addition the counting rate of the Geiger counter is scaled and telemetered. Three successful flights were made with this apparatus at a geomagnetic latitude of 70°N in July, 1954 using the Iowa balloon-launched rocket technique. Two flights gave anomalously high single Geiger-counter counting rates above 220 000 ft. The telescope rate did not show a significant increase—a result which is consistent with the observed atmospheric absorption of the soft radiation, in view of the additional material between Geiger counter and crystal. Complete data from the three flights will be shown and discussed, and measurements of the vertical cosmic-ray flux as a function of altitude will be given.

* Assisted by the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Meredith, Gottlieb, and Van Allen, Phys. Rev. 97, 201 (1955).

**A10. Double Geiger-Tube Study of Soft Radiation at Northern Latitude.*** J. A. ELLIS, M. B. GOTTLIEB, AND L. H. MEREDITH, *State University of Iowa.*—The soft radiation previously detected above 50 km in northern latitudes,[1] with a thin-walled Geiger tube carried in a balloon-launched Deacon rocket was studied further in July, 1954 using two nearly identical Geiger tubes and a photoelectric rocket-orientation indicator. One Geiger tube was shielded only by its 30 mg/cm² skin and the 160 mg/cm² wall of the rocket, and by varying amounts of atmosphere. The other Geiger tube was surrounded by an additional absorber of thickness 150 mg/cm². Two successful flights were made and the effect was detected in the second flight. After subtracting the cosmic-ray background, the ratio of counting rate for the tube without the absorber to counting rate for the tube with the absorber was about 3 for the upper part of the flight (90 to 100 km) and was about 2 around 50 km where the soft radiation was first encountered.

* Assisted by the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Meredith, Gottlieb, and Van Allen, Phys. Rev. 97, 201 (1955).

**A11. High-Altitude Rocket Measurements with Scintillation Counters at Northern Latitudes.*** ROBERT A. ELLIS, *State University of Iowa and Tennessee A. and I. State University.*—Two rocket flights of Na I scintillation crystals to about 90 km altitude were made at geomagnetic latitude 70°N in July, 1954. The crystals were flat cylinders 3.18 cm diameter and 1.0 cm thick. The counting rate of pulses larger than 1 Mev yields a value of charged particle intensity in agreement with previous Geiger counter results, i.e. $J \sim 0.5$ (cm² sec sterad)$^{-1}$. Detailed results and the interpretation of smaller pulses will be presented.

* Assisted by the Office of Naval Research and the U. S. Atomic Energy Commission.

**A12. Interpretation of Soft Radiation Observed at High Altitudes in Northern Latitudes.** J. A. VAN ALLEN, *State University of Iowa.*—The previously reported soft radiation has been further studied as reported in accompanying papers. The probability of occurrence was about 0.5 during July, 1954 at $\lambda = 70°$. Absorption mean free path is of the order of 180 mg/cm² in aluminum and 220 mg/cm² in the atmosphere. Discussion of alternative interpretations in terms of gamma rays of energy about 20 kev, electrons of energy about 1 Mev, or protons of energy about 15 Mev will be presented.

**A13. Identification of Cosmic-Ray Shower Particles in Emulsions.** A. HUSAIN, C. J. D. JARVIS,* AND E. PICKUP, *National Research Council, Canada.*—An experiment is in progress to identify medium energy particles ($pB \sim 50$ Mev $-$ 1 Bev) emitted in cosmic-ray stars formed at high altitudes in Ilford G5 emulsions, by means of grain counting and scattering. Pions, $K$-mesons (mass $\sim 950 m_e$), protons, hyperons, and deuterons have been identified, and there is some indication of particles with a mass intermediate between that of the 950-$m_e$ group and the proton group. The most recent results will be reported.

* National Research Laboratory Postdoctorate Fellow.

**A14. Experimental Results on the Arrival Times and Lateral Distribution of Air-Shower Particles.*** G. CLARK, *M.I.T.*—The experiments on the distribution of arrival times of air shower particles described by Bassi, Clark, and Rossi[1] have been extended using improved apparatus for which the

standard deviation in the determination of the difference of arrival times of two particles at two counters is $3\times10^{-9}$ second. From new data we find that the flux of "first" electrons in showers with sizes near $10^5$ particles can be represented by the function $\sim 0, t<0$ / $f(t)\sim e^{-t/\tau}, t>0$, where $\tau=(7\pm1)\times10^{-9}$ second. The mean arrival time of "first" particles which penetrate 15 cm of lead does not differ from the mean arrival time of "first" electrons by more than $5\times10^{-9}$ second. A lower limit on the average radius of curvature of the shower fronts is 400 m. The projected zenith angle distribution can be fitted by the function $I(\theta)=I_v(\cos\theta)^{10\pm1}$. An array of eight large-area electron-density detectors was operated in coincidence with the timing array for part of the time. We will present data on the lateral distribution and density fluctuations of electrons in individual showers.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Bassi, Clark, and Rossi, Phys. Rev. 92, 441 (1953).

**A15. Positive Excess of High-Energy μ Mesons.*** ROBERT B. BRODE AND MARVIN J. WEBER, *University of California, Berkeley.*—With counter spacing of 4 meters and an iron block 1.35 meters thick with a magnetic induction of 1.8 webers per square meter, it is possible to resolve the $\mu$-meson spectrum into bands between 55 and 14 Bev, mean energy 24 Bev and 14 and 4 Bev mean energy 9.2 Bev. The ratio of positive to negative $\mu$ mesons is $1.30\pm0.02$ for the band with mean energy of 24 Bev and $1.31\pm0.02$ for the band with a mean energy of 9.2 Bev. These values are higher than the measurements reported by Owen and Wilson and by Filosofo *et al.* The counting ratio in each of the energy intervals is of the order of 100 per day. Within the precision of the existing measurements the ratio of positive to negative $\mu$ mesons appears to be constant at energies above two billion volts. The decrease in this ratio below two billion can be explained by the production of $\mu$ mesons by secondary neutrons.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

## THURSDAY MORNING AT 10:00

Burgundy Room

(W. W. HAVENS, JR. presiding)

### *Neutron Physics, I*

**B1. Radiation Widths in the Slow Neutron Resonances of Iridium.*** H. H. LANDON, *Brookhaven National Laboratory.*—The parameters in the lowest-energy resonances in iridium have been determined from total cross-section measurements, using the Brookhaven crystal spectrometer. Preliminary results give the radiation width of the 0.654-ev resonance as $75\pm5$ mv. Activation measurements indicate that this resonance is most probably in $Ir^{191}$. The radiation width of the 1.305-ev resonance is $86\pm3$ mv. Activation at this resonance confirms the previous assignment by Goldhaber *et al.*[1] to $Ir^{193}$. Results for the 5.36-ev resonance, and the remaining one-level parameters for each resonance will be presented.

* Research performed under contract with the U. S. Atomic Energy Commission.
[1] Goldhaber, Lowry, and Sunyar, BNL-C-2, 96 (unclassified) (1949).

**B2. Total Neutron Cross Section of Rhenium.*** G. IGO, *Brookhaven National Laboratory.*—The resonances in rhenium at neutron energies between 1 and 14 ev have been studied with the BNL Crystal Spectrometer. The total cross-section data have been analyzed to determine the radiation width and peak cross-section parameters of the strong resonance at 2.157 ev. The method of analysis used to take account of Doppler effect and the effect of a finite resolution will be presented. The limits of error of these results will be discussed. The radiation width of the 2.157-ev resonance is 49 mv. The previously observed radiation widths, when plotted as a function of atomic weight, show a minimum of approximately 50 Mev at $A\simeq180$.

* Research performed under contract with the U. S. Atomic Energy Commission.

**B3. Slow Neutron Resonance Scattering in Indium.*** J. MOORE, *Brookhaven National Laboratory and Columbia University.*—The technique of using "thick-thin" target geometry[1] has been employed to study the scattering spectrum of indium below 10 ev. The levels at 1.458 ev, 3.85 ev, and 8.85 ev were clearly observed. Scattering from the level at 1.458 ev has been observed previously.[2,3] The values of $\Gamma_n/\Gamma$ and $\sigma_p$ can be determined for all the levels with an accuracy of about 15 percent from these data and $\sigma_0\Gamma^2$ obtained from total cross-section measurements.[4] A complete analysis is being worked out assuming independent Breit-Wigner levels and correcting each level for the presence of the others by using a method of successive approximations. An attempt is being made to make spin assignments.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. L. Foote, Jr. and J. Moore, Bull. Am. Phys. Soc. 30, No. 1, 22 (1955).
[2] B. N. Brockhouse, Can. J. Phys. 31, 448 (1953).
[3] L. B. Borst, Phys. Rev. 90, 859 (1953).
[4] V. L. Sailor and L. B. Borst, Phys. Rev. 87, 161 (1952).

**B4. Total Neutron Cross Sections of Na, K, and Rb, in the 0.03- to 10-ev Region.*** E. G. JOKI, L. G. MILLER, AND J. E. EVANS, *Phillips Petroleum Company.*—Transmission measurements have been made with the MTR-crystal spectrometer on Na, K, and Rb metal samples,[1] 8.73 cm (8.48 g/cm$^3$), 30.0 cm (26.1 g/cm$^3$), and 5.04 cm, respectively. The free-atom scattering cross sections, as determined from these data, are $3.2\pm0.1$ b for Na and $2.04\pm0.1$ b for K. The Rb data are to be corrected for a 5-weight percent Cs contamination in the sample.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] We are indebted to Dr. W. K. Ergen of the Oak Ridge National Laboratory for supplying the samples.

**B5. Resonance Parameters in Ta.*** F. B. SIMPSON, R. G. FLUHARTY, AND O. D. SIMPSON, *Phillips Petroleum Company.*—In a continuation of the Ta studies at the MTR,[1] fast chopper transmission measurements have been used to determine parameters above 10 ev. New levels have been found at 23 and 36 ev. Sets of Breit-Wigner level parameters have been determined on five levels, and fairly constant values of $\Gamma_\gamma$ are observed. The values of $\Gamma_n$ have been determined for other levels, and the ratio $\langle\Gamma_n^0\rangle/\bar{D}$ will be discussed. From a combination of crystal and fast chopper spectrometer data, the resonance absorption integral has been calculated.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Evans, Joki, and Smith, Phys. Rev. (to be published).

**B6. Total Neutron Cross Section of Np-237 in the 0.02- to 3-ev Region.*** M. S. SMITH, R. R. SMITH, E. G. JOKI, AND J. E. EVANS, *Phillips Petroleum Company.*—Previous MTR crystal-spectrometer measurements,[1] which provided evidence for the existence of a second natural Ta isotope, have demonstrated the feasibility of total cross-section measurements on samples with macroscopic cross sections as small as 0.04 $cm^2$. When a 154-mg sample of Np became available,[2] transmission measurements were made in the 0.02- to 3-ev region. The Np sample was a 0.5-$cm^3$ solution of the nitrate in $D_2O$. A special elevator-type sample changer provided for precise location of the sample in a Bragg beam 0.35 $cm^2$. Prominent resonances were found at 0.489, 1.34, and 1.49 ev. The Breit-Wigner parameters for the first resonance are $E_0 = 0.489 \pm 0.005$ ev, $\sigma_0 = 2600$ b, $\Gamma = 0.032 \pm 0.003$ ev, and $g\Gamma_n = 0.016$ mv. Values of $\sigma_0\Gamma$ for the 1.34- and 1.49-ev resonances are $\sim$29 and $\sim$140 ev·b, respectively.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Evans, Joki, and Smith, Phys. Rev. (to be published).
[2] We are grateful to Dr. Wallmann of the University of California Radiation Laboratory for providing the Np sample.

**B7. Analysis of Low-Energy Neutron-Resonance Cross Sections.*** B. MARGOLIS, O. KOFOED-HANSEN, AND E. NAGEL, *Columbia University.*—A neutron cross section formula is derived using the Wigner-Eisenbud[1] procedure with the following assumptions: (1) an average level spacing can be used, (2) the square roots of the products of the reduced neutron and radiation widths have alternating signs in order to approximate a random sign distribution, and (3) for energies near any level, the contribution from other levels is representable by average level widths. Estimates of the deviations from the one level Breit-Wigner formula in the wings of the resonances are obtained. Comparison with experimental data will be made.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] E. P. Wigner and L. Eisenbud, Phys. Rev. **72**, 29 (1947).

**B8. Recent Developments in the Analysis of Neutron Resonances and Results of Fast Chopper Measurements on Tantalum.*** V. E. PILCHER, D. J. HUGHES, AND J. A. HARVEY, *Brookhaven National Laboratory.*—The area method for the determination of resonance parameters has proved to be very useful for the analysis of neutron resonances in the ev region. However, for cases in which the samples used are neither very thick ($n\sigma_0 \gg 1$) nor very thin ($n\sigma_0 \ll 1$), the usual method of obtaining the parameters from the area requires an excessive amount of computation.[1] In order to facilitate the rapid analysis of data from a large number of resonances, we have calculated a set of universal curves relating the areas of transmission dips to resonance parameters for various values of Doppler broadening. With the aid of these curves, resonance parameters may be determined from the measured area above a transmission dip in a small fraction of the time required by the older methods. It is also a simple matter to determine the uncertainty in the parameters arising from various experimental errors. The application of the new procedure to the analysis of Brookhaven fast chopper measurements on tantalum will be discussed. In tantalum, 20 resonances were observed up to 130 ev. The average level spacing per spin state, $\bar{D}$, is 9 ev (based on the first 10 levels) and the average $\Gamma_n^0/\bar{D}$ is $(1.8 \pm 0.3) \times 10^{-4}$.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] Seidl, Hughes, Palevsky, Levin, Kato, and Sjöstrand, Phys. Rev. **95**, 476 (1954).

**B9. Fast Chopper Measurements of Radiation Widths.*** A. STOLOVY AND J. A. HARVEY, *Brookhaven National Laboratory.*—Further investigations have been made of the radiation widths of nuclear energy levels for isotopes in the regions of the neutron-magic numbers using the Brookhaven fast chopper. Neutron transmission measurements were made on low-energy resonances in the following isotopes: $Sr^{87}$, $Sb^{121}$, $Sb^{123}$, $Ba^{138}$, $La^{139}$, $Nd^{145}$, and $Pt^{198}$. The resonances were analyzed to obtain the Breit-Wigner level parameters. Good measurements of radiation widths were possible only when radiative neutron capture predominated over neutron scattering. The fluctuations in the measured radiation widths are not large, and they can be correlated with the shell model through the dependence of the radiation width on the excitation energy and the level spacing. The essential features of this dependence seem to be given by the modified single-particle transition theory of Blatt and Weisskopf, using their level density formula. Evidence from this investigation also indicates that the radiation emitted by excited nuclei is primarily electric dipole radiation.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] J. S. Levin and D. J. Hughes, Bull. Am. Phys. Soc. **30**, No. 1, 22 (1955).

**B10. Energy Distribution of Cold Neutrons Scattered by Lattice Vibrations.*** R. S. CARTER, D. J. HUGHES, AND H. PALEVSKY, *Brookhaven National Laboratory.*—Both x-rays and neutrons can be used to investigate the fundamental problem of the spectrum of the lattice vibrations of a crystal. Neutrons offer a more direct method of attacking the problem because they are available with energies comparable to those of the lattice vibrations making it possible to measure directly the energy changes resulting from the neutron interacting with the lattice. The energy distribution of the neutrons scattered inelastically by a crystal is almost completely dependent on the lattice vibrations of the crystal if the energy of the incident neutrons is small compared to the energy of the scattered neutrons. A filtered beam of neutrons has been obtained from the Brookhaven reactor with wavelengths greater than 4.5 A and a flux of about $10^4$ neutrons/$cm^2$-sec over an area of 7 square inches. Preliminary results have been obtained on beryllium and vanadium by analyzing the scattered neutrons by the gold-absorption method. The major fraction of the neutrons scattered from Be is found to have wavelengths of about 1.5 A in agreement with simple theoretical arguments. Higher energy components were also observed. The scattering of neutrons from vanadium is almost completely incoherent elastic scattering and, as expected, the major part of the scattered neutrons exhibited the same energy as the incident neutrons.

* Work carried out under contract with the U. S. Atomic Energy Commission.

**B11. Inelastic Scattering of Cold Neutrons by the Lattice Vibrations of Crystalline Solids.*** H. PALEVSKY, D. J. HUGHES, AND R. L. ZIMMERMAN, *Brookhaven National Laboratory.*—For neutrons of wavelengths longer than twice the largest lattice spacing of a crystalline sample, the Bragg condition is satisfied only in the forward direction. The measured cross section in a transmission experiment arises from the nuclear absorption, inelastic scattering from the lattice vibrations of the solid and incoherent elastic scattering. By choosing substances having small nuclear absorption and investigating the variation of the total cross section with sample temperature and neutron wavelength it is possible experimentally to determine the inelastic scattering with good accuracy. Such investigations have been carried out with the Brookhaven slow chopper for the past several years, using samples of Be, C, Mg, Al, Fe, Cu, Zr, Pb, and Bi. These have simple crystal structure and cover a wide range of masses and Debye temperatures. Typical sample temperatures varied from 100° to 1000°K and the energies of the incident neutrons corresponded to temperatures between 2.5° to 60°K. The exact theoretical calculations (assuming a Debye frequency spectrum) for these interactions is very involved, and a number of papers have been published dealing with approximation methods. The agreement of ex-

periment and theory for a few elements is good, but for most of the samples investigated the agreement with theory is poor.

* Work carried out under contract with the U. S. Atomic Energy Commission.

**B12. Neutron Velocity Distribution in an Infinite Scattering Medium with Finite Absorption.*** JOHN W. NIESTLIE, JR., AND ARTHUR I. BERMAN, *Pratt & Whitney Aircraft.*—The hardening of the neutron spectrum with respect to the Maxwellian distribution has been calculated[1] for a medium of constant scattering cross section in which small amounts of material of high absorption cross section (varying inversely with velocity) are introduced. Scattering probabilities derived by Wigner and Wilkins[2] for monatomic media whose atoms are in classical motion were used in the formulation. The integral neutron conservation equation, obtained by cutting off the distribution at an arbitrary high velocity, and introducing a source of neutrons degraded from a high velocity constant flux, was solved by an iterative method with an IBM 701 computer.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] An independent solution was recently obtained by H. D. Brown and D. S. St. John (unpublished). The problem is being solved using a Monte Carlo technique by R. Osborne and R. Coveyou.
[2] E. P. Wigner and J. E. Wilkins, Jr., Atomic Energy Commission Document 2275.

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THURSDAY MORNING AT 10:00

Exhibit Hall I

(P. KUSCH presiding)

## *Radiofrequency Spectroscopy, I*

**BA1. Hyperfine Structure in the Paramagnetic Resonances in Solutions of Manganous Salts.** JOSEPH E. GEUSIC AND DUDLEY WILLIAMS, *Ohio State University.**—Studies of paramagnetic resonance absorption by the $Mn^{++}$ ion in solutions of manganese salts have revealed well resolved hyperfine structure. The observed line pattern is predicted by the expression,

$$H = h\nu/g - Am - \frac{A^2 g\beta}{2h\nu}\{I(I+1) - M^2 + M(2M-1)\},$$

in which the symbols have their usual meaning. The value for the hyperfine splitting parameter $A = 95.3 \pm 1.0$ gauss is in agreement with the value previously obtained by Tinkham, Weinstein, and Kip[1] but in disagreement with the value reported by Schneider and England.[2] The variation of line width with concentration will be discussed.

* Supported by a contract with Office of Scientific Research, Air Research and Development Command, U. S. A. F.
[1] Tinkham, Weinstein, and Kip, Phys. Rev. **84**, 848 (1951).
[2] Schneider and England, Physica **17**, 221 (1951).

**BA2. Paramagnetic Resonance of Irradiated Hydrogen Sulfide and Hydrazine Chloride at Liquid Air Temperature.*** WILLIAM B. ARD, JR., AND WALTER GORDY, *Duke University.*—The paramagnetic resonance of solid $H_2S$ and $D_2S$ has been observed at 8900 Mc after irradiation by x-rays at 77°K. A resolved hyperfine structure is observed. A doublet with a separation of 28 gauss is found at g value 2.00 and seems to be independent of crystal orientation and isotopic substitution. Other lines with g values larger than 2 vary with crystal orientation. The doublet is tentatively interpreted as arising from the $S^+H$ radical in a $^2\Sigma_1$ state. Resonance has also been found in irradiated $N_2H_6Cl_2$. This resonance shows a hyperfine structure which has been observed over a range of about 430 gauss. A weak line, which seems to be independent of crystal orientation, is found at a field 250 gauss lower than the free electron value. It may be the lower component of the atomic hydrogen doublet. Resonances were also observed in irradiated $N_2H_4$ and $H_2Se$.

* Work supported by the Office of Ordnance Research.

**BA3. Nuclear Spin of $Rb^{81}$—Method of Measurement.*** J. P. HOBSON,† J. C. HUBBS, W. A. NIERENBERG, AND H. B. SILSBEE, *University of California.*—The zero moment method of atomic beams was applied to the measurement of the nuclear spin, magnetic moment, and hyperfine splitting of $Rb^{81}$ (4.7 hours). The isotope was produced by $\alpha$-bombardment of $BaBr_2$ in the 60-inch cyclotron. About 70 millicuries of $Rb^{81}$ were produced, and were chemically extracted with 5 mg of normal RbBr as carrier. A beam of Rb was produced from the reaction $Ca + 2RbBr \rightarrow CaBr_2 + 2Rb$. A specially designed oven loader inserted the channeled oven from air to its position under high vacuum in three minutes. The beam after passing a conventional single magnet and detector slit fell on either a hot wire detector or on a sulfur button which could be extracted from vacuum in a few seconds to be counted. The x-rays from 2 kev to 60 kev resulting from $K$-capture decay of $Rb^{81}$ were counted in a NaI—Tl scintillation counter with a very small crystal.

* Research supported by the Office of Naval Research.
† Now at National Research Council, Ottawa, Canada.

**BA4. Spin and Magnetic Moment of (4.7-Hour) Rubidium-81.*** J. C. HUBBS,† J. P. HOBSON, W. A. NIERENBERG, AND H. B. SILSBEE, *University of California, Berkeley.*—The spin and hyperfine splitting of neutron-deficient $Rb^{81}$ have been determined to be $\frac{3}{2}$ and $5000 \pm 150$ megacycles by the zero-moment method of atomic beams. From the hfs, spin, and magnetic moment of other rubidium isotopes and these values, the nuclear magnetic moment of $Rb^{81}$ is deduced to be $2.00 \pm 0.06$ nuclear magnetons. The isotope was identified from its chemistry and from its half-life and decay scheme. A study of the angular distribution of material emitted from highly channeled ovens has shown substantial agreement between experiment and the theory of Silsbee[1] for the fraction per unit solid angle of atoms emitted in the forward direction. The collection of ions and atoms on various surfaces has been investigated by tracer techniques. Sulfur is found to retain substantially all incident thermal rubidium atoms.

* Research supported by the Office of Naval Research.
† National Science Foundation Predoctoral Fellow: now at Columbia University.
[1] H. B. Silsbee, Ph.D. thesis, Harvard University, 1950.

**BA5. Fine Structure of Singly Ionized Helium.*** ROBERT NOVICK, EDGAR LIPWORTH, AND PAUL F. YERGIN,† *Columbia University.*—The energy difference ($\delta$) between the $2^3S_1$ and $2^3P_1$ states of ionized helium has been measured by a pulse technique described by Yergin *et al.*[1] As a result of an improvement in the detection efficiency, the signal-to-noise ratio has been increased by a factor of ten. In addition a study has been made of the various phenomena that determine the shape of the resonance curve. As a result of this study a number of

small corrections to the observed resonance center have been discovered and evaluated. The present value of $\delta$ for $He^+$ is 14 043±13 Mc/sec. The stated uncertainty is equal to three times the standard deviation plus an estimated 2 Mc/sec for the uncertainty in the systematic corrections. This result is consistent with the previous results[1,2] and is in good agreement with the present theoretical value of 14 047.3±2.6 Mc/sec. The relation of the present results to those obtained in hydrogen and deuterium will be discussed. Further measurements of $\delta$ in $He^+$ are in progress.

* Work supported jointly by the Signal Corps, the Office of Naval Research and the Air Research and Development Command, and the National Science Foundation.
† Present address: University of Pennsylvania.
[1] Yergin, Lamb, Lipworth, and Novick, Phys. Rev. **90**, 377(A) (1953).
[2] W. E. Lamb, Jr., and M. Skinner, Phys. Rev. **78**, 539 (1950).

**BA6. Hyperfine Structure of Gallium Isotopes in the Ground State.** A. Lurio and A. G. Prodell, *Columbia University.*—The hyperfine structure of the $^2P_{\frac{1}{2}}$ state of both $Ga^{69}$ and $Ga^{71}$ have been measured by the atomic beam magnetic resonance method. The measured values are, $\Delta\nu^{69}=2677.9875\pm0.0010$ mc/sec and $\Delta\nu^{71}=3402.6946\pm0.0013$ mc/sec. The ratio of the measured $\Delta\nu$'s equals the ratio of the magnetic interaction constants $a$ within experimental errors. Both the $^2P_{\frac{1}{2}}$ and the $^2P_{\frac{3}{2}}$ states may be characterized by a hyperfine structure anomaly constant, $\Delta=(\mu''/\mu^{69}-a^{71}/a^{69})\times(\mu^{69}/\mu^{71})$. We find that the differential constant $\delta=\Delta_{\frac{1}{2}}-\Delta_{\frac{3}{2}}=31.5\pm2.4\times10^{-6}$. The values of $\delta$ predicted by Bohr and Weisskopf[1] from a consideration of the magnetic effect of the penetration of the electron into the nucleus is $13\times10^{-6}$ (odd particle in nucleus model). The difference between the experimental and theoretical value of $\delta$ may arise from the finite distribution of the coulomb charge within the nucleus or from other effects. The hyperfine structure of the metastable $^2P_{\frac{3}{2}}$ states of $Ga^{69}$ and $Ga^{71}$ were also remeasured in view of the discrepancy between the results of Daly and Holloway[2] and those of Kusch and Becker.[3] Our results agree with those of Daly and Holloway within our present experimental error of ±3 kc.

[1] Bohr and Weisskopf, Phys. Rev. **77**, 94–98 (1950).
[2] Daly and Holloway, Phys. Rev. **96**, 539–540 (1954).
[3] Kusch and Becker, Phys. Rev. **73**, 584–91 (1948).

**BA7. Nuclear Spins and Hyperfine Separations of $Au^{198}$ and $Au^{199}$.*** J. B. Reynolds, R. L. Christensen,† D. R. Hamilton, A. Lemonick,‡ F. M. Pipkin,§ and H. H. Stroke, *Princeton University.*—The Princeton focusing atomic beam apparatus[1] has been used to measure the spin of $Au^{198}$ (2.7 days) and the spin and hyperfine separation, $\Delta\nu$, of $Au^{199}$ (3.2 days). The value of $H$ in the transition field was determined by a $K^{39}$ resonance; resonances at several values of $H$ were observed for each gold isotope. We obtain $I=\frac{3}{2}$ for $Au^{199}$, in agreement with the $d_{\frac{3}{2}}$ proton prediction of the shell model. The spin of $Au^{198}$ is 2, in agreement with Nordheim's "weak" rule applied to a $d_{\frac{3}{2}}$ proton and a $p_{\frac{1}{2}}$ neutron. $\Delta\nu$ for $Au^{199}$ is 10 850±150 mc/sec. $\Delta\nu$ for $Au^{198}$ is greater than 14 000 mc/sec. Further measurements are being made to determine $\Delta\nu$ for $Au^{198}$ as well as the signs of both magnetic moments.

* Work supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
† Whiton Fellow.
‡ Now at Haverford College.
§ Now at Harvard University.
[1] Lemonick and Pipkin, Phys. Rev. **95**, 1356 (1954).

**BA8. Nuclear Resonance Fluorescence in $Ge^{74}$ and $Pr^{141}$.*** Franz R. Metzger, *Bartol Research Foundation.*—Using a germanium metal scatterer[1] and a gaseous source of $As^{74}$, a large resonance fluorescence effect due to the 596 kev excited state of $Ge^{74}$ has been observed. Angular distribution measurements characterize the transition as quadrupole. From the magnitude of the resonance fluorescence effect a lifetime $\tau_\gamma$ of $(2.4\pm1)\times10^{-11}$ second was calculated for the 596 kev transition. This lifetime is one order of magnitude shorter than expected for an electric quadrupole transition on the basis of the single particle model. Using the 145 kev gamma rays from a source of $Ce^{141}$, resonance fluorescence from a praseodymium oxide[2] scatterer has been observed. Preliminary results indicate a lifetime $\tau_\gamma$ of $(3.5\pm1)\times10^{-9}$ second for the 145 kev magnetic dipole transition in $Pr^{141}$. This lifetime is two orders of magnitude longer than expected on the basis of the single particle model.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Loaned by the Bell Telephone Laboratories, Murray Hill, New Jersey.
[2] Loaned by Dr. F. Spedding, Ames Laboratory of the U. S. Atomic Energy Commission, Ames, Iowa.

**BA9. Spin, Magnetic Moment, and Electric Quadrupole Moment of $La^{138}$, and the Magnetic Moment of $Cl^{36}$.** P. B. Sogo and C. D. Jeffries, *University of California, Berkeley.*—By nuclear induction we have observed the nuclear magnetic resonance of the rare odd-odd isotope $La^{138}$ using both natural and enriched samples, supplied by Oak Ridge National Laboratory. The ratio of the resonance frequency to that of $La^{139}$ is $\nu(La^{138})/\nu(La^{139})=0.93407\pm0.00003$. By a detailed comparison of the relative signal amplitudes, polarities, and line widths of $La^{138}$ and $La^{139}$, and using the known moments of $La^{139}$, we find the spin $I(La^{138})=5$, and the magnetic moment $\mu(La^{138})=+(3.6844\pm0.0004)$ nm, without diamagnetic correction. From the observed thermal relaxation times and the reasonable assumption that the relaxation process is chiefly via the nuclear electric quadrupole moment $Q$ we find $Q(La^{138})/Q(La^{139})\cong3$, which yields $|Q(La^{138})|\cong2.7\times10^{-24}$ cm² from the measured value $Q(La^{139})$ of Murakawa and Kamei. Using the experimentally determined $g$ factors for the adjacent nuclei $Ba^{137}$ and $La^{139}$ we calculate on a simple $jj$ coupling model $\mu(La^{138})=+3.70$ nm We have observed the magnetic resonance from 250 $\mu$c of $Cl^{36}$, obtaining for the magnetic moment $\mu(Cl^{36})=+(1.2838\pm0.0002)$ nm. A $jj$ coupling calculation similar to the foregoing yields $\mu(Cl^{36})=1.16$ nm. This work has been supported in part by the U. S. Atomic Energy Commission.

**BA10. Nuclear Magnetic Moment and Mass of Chlorine-36.*** P. C. Fletcher and L. C. Aamodt, *Columbia University.*—The magnetic moment of the $Cl^{36}$ nucleus was measured by observing the Zeeman splitting in the electric quadrupole hyperfine pattern of the molecule $CH_3Cl^{36}$ ($J=0\rightarrow1$, $K=0$, $F=2\rightarrow2$). Its magnitude, as measured in a rectangularly cross-sectioned absorption cell, was found to be 1.32±0.08 nuclear magnetons. Its sign, determined in a circularly cross-sectioned absorption cell allowing circular polarization, was found to be positive. These observations favor the nuclear configuration $(d_{\frac{3}{2}})_N(d_{\frac{3}{2}})_P$ which is that expected from nuclear shell theory. Measurements of the quadrupole spectrum without a magnetic field gave the following information: the spin of $Cl^{36}$ was confirmed to be 2, the mass difference ratio $(M_{Cl^{36}}-M_{Cl^{35}})/(M_{Cl^{37}}-M_{Cl^{35}})$ was found to be 1.00168±0.04 percent, the molecular rotational constant for $CH_3Cl^{36}$ was found to be 13 187.604±0.015 Mc and its quadrupole coupling constant to be −15.83±0.20 Mc.

* This work supported jointly by the Signal Corps, the Office of Naval Research, and the Air Research and Development Command.

**BA11. Quadrupole Resonances of Chloro and Bromobenzene Derivatives.** P. J. Bray, *Rensselaer Polytechnic Institute,** and R. G. Barnes, *University of Delaware.*†—All available nuclear quadrupole resonance data for chloro and bromobenzene derivatives, including some work not yet published, have been correlated with the Hammett sigma parameter.[1–3] Regression lines have been fitted to the data by the method of least squares. These indicate that in the bromobenzene case the experimental values can be represented by the equation, $f=227.19+8.18\sigma$ megacycles per second. Evaluation of the correlation coefficient shows that approxi-

mately 90 percent of the observed frequency behavior may be ascribed to the sigma parameter. *Ortho*, *meta*, and *para* substituent positions correlate with nearly equal validity. In the chlorobenzene case, the correlation is less satisfactory, with only 60 percent of the frequency behavior determined by sigma in meta and para examples, and 83 percent determined in ortho examples. A brief discussion of some alternative views on this problem will be given.

* Research supported by a grant from the National Science Foundation.
† Research supported by the Office of Ordnance Research and the Research Corporation.
[1] L. P. Hammett, *Physical Organic Chemistry* (McGraw-Hill Book Company, Inc., New York, 1940).
[2] H. C. Meal, J. Am. Chem. Soc. **74**, 6121 (1952).
[3] P. J. Bray and R. G. Barnes, J. Chem. Phys. **22**, 2023 (1954).

**BA12. Nuclear Magnetic Relaxation in Ethane Derivatives.*** S. L. LINDER, *Washington University*.—It has been found that hydrogen and fluorine nuclei in certain of the ethane derivatives exhibit very long thermal relaxation times at liquid nitrogen temperature. The substances $CH_2Cl-CH_2Cl$ and $CH_2Cl-CF_2Cl$ have been examined and in both cases the proton relaxation time is about 30 seconds, while the fluorine relaxation time is about 10 seconds. The line widths of these resonances are all of the order of 10 gauss. In the Bloch notation, this situation can be described as $\alpha \ll \beta$, $\beta \gg 1$, and, for the values of $H_1$ used in this experiment, $\alpha \ll 1$. If the rf field is turned on suddenly, the derivative of the nuclear signal is observed to saturate with a time constant which can be related to $T_1$, the thermal relaxation time. The experiment permits an estimation of the saturation factor, which is a measure of the deviation of the line shape from a pure Lorentzian.

* Assisted in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

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## THURSDAY MORNING AT 10:00

## Exhibit Hall II

## (C. ZENER presiding)

## *Metals*

**C1. An Effect of Order-Disorder on the Low-Temperature Resistance Maximum.** R. W. SCHMITT, *General Electric Research Laboratory*.—The addition of Mn to a $Cu_3Au$ alloy is found to produce a maximum in the low-temperature resistance of the alloy similar to the maxima found in Cu, Ag, or Au upon adding Mn.[1] Moreover, the temperature at which the resistance maximum occurs depends on the heat treatment of the alloy in a way that suggests a connection between this temperature and order-disorder in the matrix. An alloy containing ≈0.17 atomic percent Mn has been investigated and an upward shift in the temperature of the resistance maximum of as large as 0.4°K has been observed in going from a "disordered" matrix to a "well-ordered" matrix.

[1] A. N. Gerritsen and J. O. Linde, Physica **17**, 573 (1951); **18**, 877 (1952)

**C2. Monomolecular *vs* Bimolecular Relaxation Kinetics in $Cu_3Au$ and Beta Brass.** JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories*.—Consider the elementary act of disordering in binary alloy as barrier-opposed $AB$ interchange, "wrong" configuration metastable, interchange of nearest neighbors only permitted. If a wrong $A$-atom has "right" nearest $B$-neighbors it can migrate, while remaining wrong, from its original partner and be "righted" by interchange with a wrong $B$-atom not the original partner, leading to bimolecular isothermal relaxation kinetics (cot*hat* or tan*hat* laws) as expected[1] and observed[2] for $Cu_3Au$. If wrong $A$ has only right $A$ nearest neighbors except for the original partner (wrong $B$), "righting" is only by interchange with the original partner, leading to monomolecular isothermal relaxation kinetics (exp$-at$ law): this is expected for beta brass. For comparable barrier heights and frequency factors monomolecular relaxation is much the faster by many orders of magnitude, particularly so at temperatures appreciably below $T_c$. Ease of quenching in disorder in $Cu_3Au$ and absence of disorder in severely quenched beta brass support this expectation of monomolecular relaxation kinetics for the latter.

[1] J. Rothstein, Phys. Rev. **94**(A), 1429 (1954).
[2] F. Burns, Phys. Rev. **94**(A), 1429 (1954).

**C3. Thermoelectric Powers of some Palladium Alloys.** J. C. TAYLOR AND B. R. COLES,* *Imperial College, London* (introduced by J. E. Goldman).—Thermoelectric powers ($S$) have been measured in the range 0° to −200°C for the palladium-silver alloys and for some palladium-rhodium alloys. In the former system $S$ is found to be highly sensitive to the presence of unoccupied $d$-band states. A marked variation of $S$ with composition occurs in alloys with more than 90 percent of either element. This behavior can be ascribed to a contribution to conduction by $d$-band holes in the palladium-rich alloys, and to departure of the Fermi surface from an absolutely spherical form as the electron concentration increases in the silver-rich alloys. Estimates of $S$ for the pure metals, made on the basis of simple theoretical models which ignore these complications, show close agreement with values obtained by extrapolating experimental results for alloys where these effects are absent. The composition dependence of $S$ in alloys containing no $d$-band holes supports the view[1] that the relaxation time for impurity scattering has an energy dependence different from that for lattice scattering. Initial additions of rhodium to palladium produce effects which are consistent with the behavior in the alloys with silver, but larger additions give anomalous effects.

* On leave of absence at Carnegie Institute of Technology.
[1] C. A. Domenicali and F. A. Otter, Phys. Rev. **95**, 1134 (1954).

**C4. Thermodynamic Properties of Alpha Ag-Cd and Alpha Au-Cd Alloys.*** P. HERASYMENKO, *New York University*.—Measurements of partial pressure of cadmium were made over alpha solid solutions in the Ag-Cd and Au-Cd systems. Thin weighed wires of pure silver or gold were placed at different positions along a temperature gradient in an evacuated quartz tube in which a constant pressure of cadmium vapor was maintained. The wires absorbed cadmium until the alloys formed reached equilibrium with the vapor. Cadmium content was obtained from the weight increase of the wires. Several hundred alloys were obtained in the alpha field of each system at different cadmium pressures and for different temperature ranges (mostly above 550°C). The evaluation shows that sharp increases in relative partial entropy of cadmium occur at 8.33 at. percent Cd in the Ag-Cd system, and at 16.66 and 25.0 at. percent Cd in the Au-Cd system. The results indicate that a considerable ordering takes place in the alpha (f.c.c.) solid

solutions at compositions where the ratio of solute to solvent atoms is 1/11, 1/5, and 1/3.

* The study was sponsored by the Office of Ordnance Research.

**C5. Mutual Solubilities of Iron and Osmium.** S. S. SIDHU AND D. D. ZAUBERIS, *Argonne National Laboratory.*—The electronic structures of 3*d* and 4*s* shells of iron are identical with those of 5*d* and 6*s* of osmium. In the "free" or gaseous state each *d*-shell contains 6 electrons and each *s*, 2. The metallic radii of iron are about 6.1 percent and 6.7 percent smaller than those of osmium for coordination numbers of 8 and 12 respectively. These factors favor an extensive solubility of one metal in the other. From a series of substitutional solid solutions of iron in osmium and osmium in iron, prepared at 2000°–2700°C and cooled to room temperature, it is found that iron dissolves in osmium to the extent of 80 atomic percent, and osmium in iron to about 10 atomic percent. The region between 80 and 90 atomic percent iron in osmium is a transformation region in which the two phases coexist. As iron dissolves in osmium the osmium lattice contracts, but with increasing solubility of osmium in iron the iron lattice expands. At room temperature the volumes of the unit cells of osmium metal and of electrolytic $\alpha$ iron used in this investigation were: $27.98\times10^{-24}$ cm³ and $23.49\times10^{-24}$ cm³ respectively. At the solubility limits they approached the value of approximately $24\times10^{-24}$ cm³.

**C6. Small-Angle X-Ray Scattering from Cold-Worked Metals.*** R. H. NEYNABER, W. G. BRAMMER, AND W. W. BEEMAN, *University of Wisconsin.*—The diffuse small angle scattering from cold-worked metals is presumed caused by the collection of lattice vacancies into small cavities. Some of our recent experimental results are difficult to explain on this model. We observe in annealed Ni, Cu, and Al foils sharp scattering peaks at 1° or 2° scattering angle (Fe $K_\alpha$ radiation). We believe these arise from two successive Bragg scatterings by adjacent and slightly-tilted grains. We will discuss the possibility that some or all of the diffuse scattering in cold-worked foils is due to a similar mechanism. Foils cold worked at liquid air temperature show immediately the usual diffuse scattering. There is no evidence for the growth of cavities by the diffusion of vacancies as the foil is warmed. Below annealing temperatures the intensity of the diffuse scattering decreases and increases reversibly with increasing and decreasing foil temperature. This is understandable with double scattering (the Debye factor) but difficult with a cavity model. Arguing against double scattering is our failure to find scattering curves intermediate between the occasional sharp peaks from annealed samples and the continuous diffuse scattering from slightly cold-worked samples.

* Supported by the Office of Scientific Research, Air Research Development Command, and the Wisconsin Alumni Research Foundation.

**C7. Dislocation Relaxations at Low Temperatures and the Limiting Shear Stress in Metals.** W. P. MASON, *Bell Telephone Laboratories.*—Recent measurements of the ultrasonic attenuation[1,2] in four face-centered metals have shown relaxations in the temperature range from 35°K to 150°K. For lead the relaxation frequency follows Eq. (1a). At higher temperatures, a loss shown by Eq. (1b) results for lead. Thus

$$\omega_0 = 2\pi f_0 = 2.9\times10^9 e^{-790/RT} \quad (1a); \qquad Q^{-1} = 1.8 e^{-4350/RT}. \quad (1b)$$

TABLE I.

| Metal | Temp. of max. atten. | Act. eng. cal/mole | b in A° | $\mu$ dynes/cm² | $T_{13_0}$ dynes/cm² | $T_{13_0}/\mu$ |
|---|---|---|---|---|---|---|
| Pb | 35°K | 790 | 3.5 | $7.3\times10^{10}$ | $3.9\times10^{6}$ | $5.3\times10^{-4}$ |
| Cu | 85°K | 1910 | 2.55 | $4.0\times10^{11}$ | $1.9\times10^{8}$ | $4.7\times10^{-4}$ |
| Al | 100°K | 2260 | 2.86 | $2.5\times10^{11}$ | $1.6\times10^{8}$ | $6.4\times10^{-4}$ |
| Ag | 60°K | 1350 | 2.88 | $2.5\times10^{11}$ | $1.0\times10^{8}$ | $4.0\times10^{-4}$ |

Furthermore, 790 cal/mole correlates with the energy required to displace a dislocation loop from one minimum energy to an adjacent one against the limiting shearing stress $T13_0$. From the activation energies measured one can determine the limiting shearing stress $T13_0$ for the four metals as shown by Table I.

[1] P. C. Bordoni, J. Acoust. Soc. Am. **26**, 495 (1954).
[2] H. E. Bömmel, Phys. Rev. **96**, 220 (1954).

**C8. Conductivity of Thin Films in a Longitudinal Magnetic Field.** ERNEST KOENIGSBERG AND LEON FINDLEY, *Midwest Research Institute.*—The conductivity of thin *films* in a strong magnetic field (i.e., radius of curvature of electron paths less than half the film thickness) can be expressed in closed form.[1] We have calculated the conductivity in weak fields by numerical integration of the expression resulting from the free electron approach described in reference 1. This integration was performed on the Card Program Calculator at Midwest Research Institute. Calculation errors range from less than 1.0 percent for thick films to 3.0 percent (due to slow convergence) for relatively thin films in very weak fields. Comparison is made with Chamber's[2] results for thin *wires*. In a given field, the conductivity of a film is greater than that of a wire of the same material whose diameter is equal to the film thickness. At present, experimental results are not available for comparison.

[1] E. Koenigsberg, Phys. Rev. **91**, 8 (1953).
[2] R. G. Chambers, Proc. Roy. Soc. (London) **A202**, 378 (1950).

**C9. Tensile Strengths of Silver Films of Various Thicknesses at Different Temperatures.*** J. B. BREAZEALE, W. L. BART, AND J. W. BEAMS, *University of Virginia.*—Silver films are electrodeposited on the periphery of cylindrical ferromagnetic rotors which are then spun until the films are thrown off. Both tensile strength and adhesion may be measured by this method,[1] but in these experiments care was taken in the electrodeposition process to reduce adhesion to a negligible value. The rotors were magnetically suspended in glass vacuum chambers and driven by rotating magnetic fields. At low temperatures the vacuum chamber was surrounded by two dewars. The outer Dewar contained liquid nitrogen; and the inner one contained liquid helium or liquid nitrogen, depending upon the desired operating temperature. At room temperature the tensile strength is independent of film thickness and equal to about that of bulk silver for thicknesses from $10^{-3}$ cm to approximately $2.9\times10^{-5}$ cm. For film thicknesses less than about $2.9\pm0.3\times10^{-5}$ cm (the exact value depends slightly upon the plating current) the tensile strength increases many fold. At liquid nitrogen temperature for film thicknesses from $10^{-3}$ cm to roughly $2.9\times10^{-5}$ cm the tensile strength is constant and equal to approximately $23\times10^{8}$ dynes/cm². For thinner films a large increase in tensile strength is observed.

* Supported by the Office of Ordnance Research.
[1] Beams, Walker, and Morton, Phys. Rev. **87**, 524 (1952).

**C10. A Technique for the Study of Thin Metallic Films.** R. L. KELLY, *Stanford Research Institute.*—A method will be described which permits the determination of resistivity and thermoelectric emf of thin metallic films. The films are formed by vacuum evaporation in a sealed-off glass tube and kept under high vacuum during the electrical measurements. The tube will be described in detail and some preliminary data on iron films will be presented.

**C11. Micromachining with Virtual Electrodes.** A. UHLIR, JR., *Bell Telephone Laboratories.*—Minute holes have been drilled in germanium, iron, copper, silver, and tungsten carbide by a new technique for machining by electrolytic etching. The flow of current is localized by a nonconducting partition in the electrolyte. The partition may be a glass tube drawn down to a tip as small as one micron in diameter. A variety of shapes can be produced by moving the tip with respect to the work. Localized plating has also been accomplished with the technique.

THURSDAY MORNING AT 10:00

Continental Room

(N. P. HEYDENBURG presiding)

## *Fission; Coulomb Excitation*

**CA1. Energy Spectrum of the Delayed Gamma Rays from Uranium Photofission.*** J. M. WYCKOFF AND H. W. KOCH, *National Bureau of Standards.*—The delayed gamma rays from uranium samples irradiated by 18.5 Mev electrons from a 50 Mev betatron were studied in the range of 30 kev to 5 Mev with a 4 in. long, 5 in. diameter, NaI(Tl) spectrometer. After bombardment times of 1, 2, 10, and 90 minutes, photographs of two ten-channel pulse-height analyzers taken at regular intervals recorded the pulse-height distribution and decay rate. The location of the spectrometer was such that there was no neutron activation of the crystal. Three uranium samples, 0.02, 0.09, and 0.30 cm thick, were used in order to assess the effects of buildup of gamma intensity in the bombarded target and self-absorption, backscattering, and self-excitation of the $K\alpha$ x-rays on the measured spectrum. The measured energy spectrum above 360 Kev during the first 100 seconds was a fairly smooth straight line on a semi-log plot dropping 3.5 decades by 5 Mev. In the delay time interval between 10 and 42 minutes the slope of the exponential spectrum decreased, thus decreasing the mean and the apparent maximum energy. An estimate of the number of gammas per fission above 200 kev is 2.7.

* Supported by the Department of Defense, Air Force Special Weapons Project.

**CA2. Neutron Induced Fission Excitation Curve for $Am^{241}$.*** R. A. NOBLES, R. L. HENKEL, AND R. K. SMITH, *Los Alamos Scientific Laboratory.*—The $Am^{241}$ fission cross section has been measured for several neutron energies between 0.5 and 7 Mev by simultaneously counting fission events from known foils of $Am^{241}$ and $U^{235}$ irradiated by the same neutron flux. $U^{235}$ fissions were counted by a conventional ionization chamber. Due to the high specific activity of $Am^{241}$, a fast counting system was developed to prevent obscuring the fission pulses by multiple pile-up of alpha pulses. The $Am^{241}$ pulses were counted in a xenon scintillation counter using a tetraphenylbutadiene loaded plastic film to shift the ultraviolet radiation to the visible spectrum for viewing by an RCA-6342 photomultiplier. Pulse height stability was achieved by maintaining the temperature of this counter at 0°C. The pulse output of the photomultiplier was clipped to $2\times10^{-9}$ second, amplified sent to a fast crystal discriminator which was biased to remove alpha pulses. The remaining fission pulses were lengthened to 1 μsecond, amplified and counted with conventional circuits. Using the known $U^{235}$ fission cross section, the excitation curve for $Am^{241}$ was determined. The cross section has a threshold at 0.5 Mev neutron energy, rises until 1.5 Mev, is constant up to 6 Mev and rises above 6 Mev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**CA3. Angular Distribution of Fragments from Neutrons-Induced Fission of $U^{235}$.*** J. E. BROLLEY, JR., AND R. L. HENKEL, *Los Alamos Scientific Laboratory.*—$\sigma_f(0°,E_n)/\sigma_f(90°,E_n)$ for $U^{235}$ was measured at a number of neutron energies from the threshold near 1 Mev to 20 Mev. A double fission chamber whose common center high-voltage electrode was also a collimator[1] served to detect fissions in a given direction. A coincidence requirement between the two chambers served to minimize background effects. In the threshold region the anisotropy rises rapidly to a maximum and then declines. Thereafter it exhibits the same behavior as $U^{234}$, climbing rapidly up to seven Mev and slowly declining from 14 to 20 Mev. At seven Mev the angular distribution $\sigma_f(\theta,7)$ has a shape of the form $1+A\cos^2\theta+B\cos^4\theta$, with the cosine fourth term dominant, similar to the curve for $U^{235}$ previously obtained.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Brolley, Dickinson, and Henkel, Phys. Rev. 95, 651 (1954).

**CA4. Spontaneous Fission Neutron Multiplicities.*** R. V. PYLE, D. A. HICKS, AND JOHN ISE, JR., *University of California, Berkeley.*—Further measurements of the prompt neutron multiplicity spectra from the spontaneous fission of some of the actinides have been made in a liquid scintillator moderator and detector.[1] Using the average number of neutrons per spontaneous fission of $Cf^{252}$, $\bar{\nu}=3.53\pm0.15$, we found the efficiency for detecting one neutron to be $\epsilon=0.772\pm0.029$. The data from two nuclides have been analyzed and the ratio $\bar{\nu}$ $Cf^{252}/\bar{\nu}$ $Cm^{244}=1.344\pm0.015$ obtained (probable errors shown throughout), giving $\nu$ $Cm^{244}=2.63\pm0.11$. Higgins *et al.* have measured $\bar{\nu}$ $Cm^{244}=2.60\pm0.12$. If $P(n)$ is the observed multiplicity distribution and $F(\nu)$ is the actual distribution,

$$F(\nu)=\sum_{n=\nu}^{n=n_{max}} P(n)\left[\frac{n!}{\nu!(n-\nu)!}\right]\epsilon^{-n}(\epsilon-1)^{n-\nu}.$$

Based on 6594 $Cm^{244}$ fissions and 5429 $Cf^{252}$ fissions, the values of $F(\nu)$ (normalized to unity) are

| $\nu=$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| $Cm^{244}$ | 0.013 ±0.006 | 0.140 ±0.021 | 0.315 ±0.019 | 0.340 ±0.018 | 0.157 ±0.021 | 0.030 ±0.006 | 0.004 ±0.002 | 0.0009 ±0.0006 |
| $Cf^{252}$ | 0.005 ±0.002 | 0.032 ±0.012 | 0.145 ±0.032 | 0.336 ±0.022 | 0.304 ±0.014 | 0.117 ±0.016 | 0.053 ±0.010 | 0.003 ±0.002 |

* This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] Hicks, Ise, and Pyle, Phys. Rev. 97, 564 (1955).

**CA5. Coulomb Excitation of States in Thallium and Lead.** P. H. STELSON AND F. K. MCGOWAN, *Oak Ridge National Laboratory.*—Gamma rays of 205-, 279-, and 410-kev energy are observed when thallium is excited by proton bombardment. Coincidence measurements indicate that 410-kev $\gamma$ rays are coincident with both the 205- and 279-kev $\gamma$ rays. It is thought that states of 279- and 682-kev energy are excited in $Tl^{203}$, and states of 205- and 615-kev energy are excited in $Tl^{205}$. The reduced transition probabilities for $E2$ excitation, $B(E2)$, are $(13.5\pm2.7)\times10^{-50}$ cm$^4$ $e^2$ and $(14.6\pm2.9)\times10^{-50}$ cm$^4$ $e^2$ for the 279- and 682-kev states in $Tl^{203}$, respectively. The values of $B(E2)$ and information obtained from studies of the decay of $Hg^{203}$ and $Pb^{203}$ give evidence that the $B(M1)$ for the 279-kev state is a factor of 2000 less than single particle estimate and that the $B(E2)$ for the 410-kev transition is 100 times larger than that expected for a transition between single-particle proton states. Gamma rays of 570- and 810-kev are observed when lead is excited by proton bombardment. The yield of the 810-kev $\gamma$ ray increased when radiogenic lead enriched to 88 percent $Pb^{208}$ was bombarded. These $\gamma$ rays are thought to result from the excitation of the first excited states of $Pb^{207}$ and $Pb^{206}$. The $B(E2)$ for excitation of the 570-kev and 820-kev states are $\left(2.8^{+0.6}_{-1.1}\right)\times10^{-50}$ cm$^4$ $e^2$ and $\left(13^{+2.6}_{-4.5}\right)\times10^{-50}$ cm$^4$ $e^2$, respectively.

**CA6. Electric Excitation of Palladium, Cadmium, and Molybdenum by Protons.*** GEORGE PAULISSEN AND HANS MARK, *M.I.T.*—Energy levels in enriched isotopes of cadmium, palladium, and natural molybdenum have been studied by electric excitation with protons. The following $\gamma$ rays are observed: $Pd^{108}$, 270 and 430 kev; $Pd^{106}$, 500 kev; $Pd^{105}$, 425 kev; $Pd^{110}$, 365 kev; $Cd^{113}$, 290 kev; $Cd^{114}$, 545 kev. A 199 kev $\gamma$ ray from natural molybdenum is observed which is probably due to a previously observed[1,2] level in $Mo^{98}$. Energies of the levels in the even $A$ isotopes of palladium and cadmium increase with decreasing neutron number while the reduced transition probabilities decrease. The reduced transition probability of the 270-kev level in $Pd^{105}$ is seven times smaller than that of the 430-kev level. Coincidence experiments and yield curve measurements are in progress on a number of odd $A$ isotopes where two or more $\gamma$ rays are observed to measure branching ratios and clarify level structures.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **93**, 351 (1953).
[2] Huber, Medicus, Preiswerk, and Steffen, Phys. Rev. **73**, 1211 (1948).

**CA7. Internal Conversion Electrons from Electric Excitation.*** E. M. BERNSTEIN AND H. W. LEWIS, *Duke University.*—Using a magnetic beta-ray spectrometer similar to the one used by Huus and Bjerregaard,[1] we have observed the internal conversion electrons from electric excitation of several nuclei. Alpha particles and protons of energy 2–4 Mev were used as the bombarding particles. The elements and levels investigated were: Mn, 128 kev; Ag, 320 kev; 420 kev; Ta, 137 kev, 166 kev; W, 102 kev, 112 kev, 124 kev; Au, 77 kev, 191 kev, 277 kev. The $K/L$ conversion ratio for the Au 277 kev line leads to a 60 percent $M1$ and 40 percent $E2$ mixture for the transitions from this level to the ground state. This is in agreement with the gamma-ray angular distribution measurements of Cook *et al.*[2] Electron spectra and $K/L$ ratios for other elements will be discussed.

* This work was supported by the U. S. Atomic Energy Commission.
[1] T. Huus and J. Bjerregaard, Phys. Rev. **92**, 1579 (1953).
[2] Cook, Class, and Eisinger, Phys. Rev. **96**, 658 (1954).

**CA8. Angular Distribution of Gammas from Coulomb Excitation of Thin Platinum.*** W. I. GOLDBURG, *Duke University.*—Measurements have been made of the angular distribution of gamma rays from spin 2 levels near 345 kev resulting from proton bombardment of natural platinum. Preliminary analysis of the data indicates that the proton energy dependence of the anisotropy is more rapidly changing[1] than the predictions of present Coulomb excitation theory.[2,3] The proton energy range was 2–4 Mev. The 0.0001-inch platinum was backed by 0.005-inch uranium. The bremsstrahlung contribution from the backing was measured and subtracted out.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] P. H. Stelson and F. K. McGowan, Bull. Am. Phys. Soc. **29**, No. 7, 34 (1954).
[2] K. Alder and A. Winther, Phys. Rev. **91**, 1578 (1953).
[3] K. Alder and W. Winther, Phys. Rev. **96**, 237 (1954).

**CA9. Energy Levels in Ru, Pd, and Cd by Coulomb Excitation.** G. M. TEMMER AND N. P. HEYDENBURG, *DTM, Carnegie Institution of Washington.*—We have excited the following gamma rays in Ru, Pd, and Cd nuclei by 6-Mev alpha-particle bombardment (*mass number*, followed by transition energy in kev). *Ru: 100*, 540; *102*, 473; *104*, 355. *Pd: 104*, 550; *105*, 266, and 433; *106*, 510; *108*, 424; *110*, 370. *Cd: 110*, 654; *111*, 340; *112*, 620; *113*, 290, and 550(?); *114*, 550; *116*, 508. Enriched isotopes[1] were used for Pd and Cd. All gamma rays in the even-even nuclei represent transitions to the first-excited $2^+$ states. Their transition probabilities (lifetimes) have been determined and will be presented. None of the lifetimes can be measured with presently available coincidence techniques ($\lesssim 10^{-11}$ sec). The lifetimes are of the order of 20 times *faster* than would be expected on the basis of single-particle transitions. Both the positions and lifetimes of these states are found to follow systematic trends interpretable on the basis of "deformation" of these nuclei.[2] A number of these $E2$ transitions as well as some in the odd-mass nuclei had not been observed before.

[1] Kindly lent by G. Scharff-Goldhaber.
[2] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953).

**CA10. Energy Levels in Ti, Fe, Ge, and Mo by Coulomb Excitation.** N. P. HEYDENBURG AND G. M. TEMMER, *DTM, Carnegie Institution of Washington.*—We have observed Coulomb-excited gamma rays with 6-Mev alpha particles on Ti, Fe, Ge, and Mo. Enriched targets (supplied by Oak Ridge) were used in the case of Mo; for the other elements, the identification was made from known transitions. The following gamma rays (energies in kev) were observed: $Ti^{48}$, 750 and 990; $Ti^{46}$, 890; $Fe^{56}$, 854; $Ge^{72}$, 830; $Ge^{74}$, 590; $Mo^{98}$, 786; $Mo^{100}$, 528. With the exception of the 750 kev line in $Ti^{48}$, all lines are due to quadrupole excitation of first-excited $2^+$ levels. Transition probabilities will be given for these gamma rays. The excitation curve of the 750 kev line of $Ti^{48}$ was not consistent with Coulomb excitation of this energy and has been assigned to the reaction $Ti^{48}(\alpha,n\gamma)Cr^{51}$; a gamma ray of the same energy was also observed in the reaction $V^{51}(p,n\gamma)Cr^{51}$.[1] Results for $Ge^{76}$ and $Mo^{96}$ will also be reported.

[1] A neutron group to this level was previously seen by Stetson, Preston, and Goodman, Phys. Rev. **80**, 287 (1950).

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## THURSDAY MORNING AT 9:30

## Caribar Room

## (C. N. YANG presiding)

### *Theoretical Physics, I; Meson Theory*

**D1. Numerical Calculation of Meson-Nucleon Scattering.*** M. H. KALOS, *Cornell University*, AND R. H. DALITZ, *Institute for Advanced Study.*—The solution of the integral equations for pion-nucleon scattering proposed by Dyson *et al.*[1] has been programmed for the UNIVAC computer,[2] paying particular attention to the singular nature of these equations. Phase shifts obtained behave qualitatively in accord with the rough solutions previously given. The wave functions and phase shifts will be presented for the $s$-, $p$-, $d$-states for which renormalization is not necessary, for energies up to 1 Bev. Calculations will also be presented for the corresponding integral equations of the relativistic $p$-wave theory in which the nucleon pair-creation graphs are omitted.

* This work was supported by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Dyson *et al.*, Phys. Rev. **95**, 1644 (1954).
[2] The cooperation of the staff of the U. S. Atomic Energy Commission Computing Facility at New York University is gratefully acknowledged.

**D2. Scattering of Pions by Nucleons in Intermediate Coupling.** M. H. FRIEDMAN AND T. D. LEE, *Columbia University.*—The scattering of pions from nucleons has been investigated by considering a symmetrical pseudoscalar meson field coupled to an extended fixed nucleon using gradient coupling. In treating this Hamiltonian one uses the intermediate coupling approximation[1] which is based on a variational procedure and does not depend on the strength of the coupling constant nor the number of mesons in the field. The problem divides into two parts. The first is the solution of the ground state (i.e., physical nucleon) using the Tomonoga approximation.[2] In order to describe the scattering of a meson by a physical nucleon one multiplies this ground-state wave function by a scattering function for the meson. This latter is then determined by a variational technique. The resulting $\alpha_{33}$ phase shift agrees with experiment, if the coupling constant $f^2=0.712$ and the cut-off $\omega_{max}=6.21\mu$ where $\mu$ is the meson mass. (This corresponds to a renormalized coupling constant $f_r^2=0.105$.) The $\alpha_{31}$ and $\alpha_{11}$ phase shifts are small, *e.g.* being $-1.60°$ and $5.99°$ respectively at 200 Mev.

[1] T. D. Lee and R. Christian, Phys. Rev. **94**, 1760 (1954).
[2] S. Tomonaga, Progr. Theoret. Phys. **2**, 6 (1947).

**D3. Correlation of Meson-Nucleon Scattering and Nuclear Forces.** ABRAHAM KLEIN* AND BRUCE H. MCCORMICK, *Harvard University.*—The general form of the interaction kernel for the relativistic two-nucleon equation has been constructed by means of the technique of functional differentiation with respect to external sources. If the nonlinear propagation of mesons (meson-meson interaction) can be neglected, the corresponding potential can be expressed completely in terms of the meson scattering and production matrices for the individual nucleons (off the energy shell) and of the meson Green's functions. The circumstance can be exploited to obtain information about the fourth-order nuclear forces, for example, by making a momentum-energy expansion of the meson-nucleon scattering amplitude and choosing the coefficients to fit the data in the low-energy region. This procedure has in effect already been applied to the isotopic-spin independent part of the *S*-wave scattering.[1] It can equally well be applied to the isotopic-spin dependent *S*-wave scattering and the *P*-wave scattering. The corresponding modifications of the long-range nuclear forces will be discussed.

* Society of Fellows.
[1] A. Klein, Phys. Rev. **95**, 1061 (1954).

**D4. Effective Range Analysis of the Pion-Nucleon *S*-Waves.*** H. P. NOYES, *University of Rochester.*—The photomeson-Panofsky effect result[1] that $|a_1-a_3|/k=0.19$ ($k=p_\pi/\mu c$) and low-energy scattering data[1] imply $a_1$ increases more rapidly than $k$ below 60 Mev. Then either the effective range is negative, implying at least two bound states of $I=1/2$, or shape dependent corrections are enormous, requiring a pathological interaction. If, however, interpretion of the Panofsky effect is in error due (for example) to charge dependent corrections, all other data[1] are consistent with $a_1\sim 0.173k$, $a_3\sim -0.097k$. Introducing a hard core,[2] the shape independent approximation may be written $a_l=\mathrm{ctn}^{-1}(-1/a_lk+r_{0l}k/2)-r_{0l}k$. If one fits the slopes and $a_1=+10°$, $a_3=-13°$ at $k=1.3$, the curves are essentially independent of $r_{03}$ if $r_{03}\lesssim\hbar/\mu c$. The parameters (units $\hbar/\mu c$) are

| $r_{03}$ | $a_1$ | $r_{01}$ | $a_3$ | $r_{03}$ |
|---|---|---|---|---|
| 0 | −0.434 | 0.261 | −0.564 | 0.661 |
| 1 | −0.222 | 0.049 | −0.322 | 0.419 |

* Work supported in part by the U. S. Atomic Energy Commission.
[1] For recent data see *Proceedings of the Fifth Annual Rochester Conference* (Interscience Publishers, Inc., New York, 1955) (to be published).
[2] H. P. Noyes and A. E. Woodruff, Phys. Rev. **94**, 1401 (1954) and references.

**D5. Energy Distribution of $\gamma$ Rays from $\pi^0$ Decay.*** R. M. STERNHEIMER, *Brookhaven National Laboratory.*—The energy distribution of $\gamma$ rays resulting from the decay of $\pi^0$ mesons produced by a high-energy proton beam is related in a simple manner to the differential cross-section $f(E_\pi,\theta_\pi)$ for $\pi^0$ production, where $E_\pi=\pi^0$ total energy and $\theta_\pi=$angle of $\pi^0$ to the incident beam. The angle $\psi$ in the laboratory system between the observed $\gamma$ and the decaying $\pi^0$ must be $\lesssim\psi_{max}=\sin^{-1}(\bar{k}/k)$, where $k=$laboratory energy of $\gamma$, $\bar{k}=\gamma$ energy in $\pi^0$ rest system. At high $\gamma$ energies, $\psi_{max}$ is small (e.g., 3.9° for $k=1$ Bev). Hence the $\gamma$-energy distribution for large $k$ at an angle $\theta_\gamma$ to the beam involves only values of $f(E_\pi,\theta_\pi)$ for a narrow range of $\theta_\pi\approx\theta_\gamma$. If $P(k,\theta_\gamma)$ is the number of $\gamma$ rays per unit energy interval $dk$ and per unit solid angle at $\theta_\gamma$, $f(k,\theta_\gamma)$ is given by $-(k/2\pi N)\partial P(k,\theta_\gamma)/\partial k$, where $n=$number of incident protons, $N=$number of target nuclei/cm$^3$. This expression is valid for $k\gtrsim 500$ Mev and can be used to obtain $f(E_\pi,\theta_\pi)$ from measurements with a $\gamma$-ray spectrometer set at various angles to the proton beam. This result has been extended to an arbitrary two-body decay.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**D6. Pion Production in Proton-Proton Scattering.*** D. B. LICHTENBERG, *University of Illinois.*—A calculation of the cross section for the reaction $p+p\rightarrow\pi^++d$ has been carried out, using the cut-off form of the Yukawa theory.[1] The diproton and deuteron wave functions have been treated phenomenologically. Two types of terms have been taken into account: (1) those due to direct emission of the pion and (2) those due to resonance scattering of the pion by the proton in the state of angular momentum 3/2 and isotopic spin 3/2.[2] These terms were found to be of comparable magnitude. Since the diproton state is one of high energy, the results are very sensitive to the details of the wave functions chosen for the deuteron and diproton, but with any reasonable choice, the correct qualitative features of the $p$-wave part of the production amplitude emerge. In particular, the absolute value of the experimental cross section is consistent with a coupling constant of the same order as that determined by pion-nucleon scattering and photoproduction.

* Supported in part by the Office of Naval Research.
[1] G. F. Chew, Phys. Rev. **95**, 1669 (1954).
[2] K. A. Brueckner, Phys. Rev. **86**, 106 (1952).

**D7. Pion Production for Polarized Protons.** F. MANDL AND T. REGGE, *University of Rochester* (introduced by R. E. Marshak).—The production of pions and deuterons in proton-proton collisions is analyzed using the statistical operator methods. We derive (1) the production cross section for $s$-, $p$-, and $d$-waves and (2) the polarization of the deuteron for both polarized and unpolarized incident protons with the restriction to $s$- and $p$-waves. The deuteron polarization gives new information about the production amplitudes for an unpolarized proton beam for the $p$-wave production only and for a polarized one for $s$-waves as well. With polarized protons a triple-scattering experiment is required. The experimental possibilities of the triple scattering experiment (in the energy-range 400 to 600 Mev) will be discussed.

**D8. Pion Production in Electron-Proton Collisions.*** R. H. DALITZ, *Institute for Advanced Study.*—The main part of the direct pion production from protons by the virtual electromagnetic field of a scattered electron may be predicted from the pion-photoproduction data, if only the outgoing pion is measured, since small angle scattering in which this field is transverse then predominates. New information is contained in the deviations from such an estimate; these deviations reflect (a) the momentum dependence of the (off-diagonal) matrix elements for excitation by the transverse field and (b) the electric transitions induced by the longitudinal field. Transverse and longitudinal excitations will generally interfere and, since the momentum transfer is large, the matrix elements (b) are different from those for the corresponding

transverse excitations. Photoproduction data and matrix-element estimates based on fixed-source meson theory suggest that the observable deviations will give information mainly on the momentum dependence of the $M1$ excitation of the resonant state and on the longitudinal $E1$ excitation. The experimental data available will be discussed.

* This work has been supported by the program of the Office of Naval Research at Stanford University and Cornell University.

**D9. A Model for Multiple Meson Production.** E. M. HENLEY, *University of Washington*, AND T. D. LEE, *Columbia University*.—A quantum-mechanical model, analogous to the classical treatment of Lewis, Oppenheimer, and Wouthuysen,[1] is proposed to study the production of mesons in nucleon-nucleon collisions. The colliding nucleons are pictured as bare cores surrounded by arbitrary numbers of mesons. The structure of the meson cloud surrounding each core and the scattering states for various numbers of mesons are determined by an intermediate coupling calculation. The strength of the meson-nucleon coupling constant and the size of the core are determined by comparison with meson-nucleon scattering experiments. In the collision process, mesons are produced by an exchange of ordinary spin and isotopic spin between the cores. Although absolute cross sections cannot be obtained from this model, production ratios for various processes are completely determined. Results will be presented for the production of one and two mesons at collision energies of the order of a few Bev.

[1] Lewis, Oppenheimer, and Wouthuysen, Phys. Rev. **73**, 127 (1948).

**D10. Structure of the Mesonic Cloud Associated with a Nucleon.** G. SALZMAN, *University of Illinois*.—Experimental evidence for the spatial extent of the charges and currents associated with a physical nucleon is becoming available. The effects of this extension may, for each nucleon, be described in terms of two invariant functions (form factors) $F_1$ and $F_2$, where $\epsilon_0 F_1$ is the nucleon's effective charge, $\epsilon_0$ its static charge, $\mu_0 F_2$ its effective anomalous magnetic moment, and $\mu_0$ its static anomalous magnetic moment. The functions $F_1$ and $F_2$ may be expressed as power series in $(\Delta p)^2[=\Delta p_\nu \Delta p_\nu]$, the square of the four momentum transferred to the nucleon in the collision under discussion. The terms of $F_1$ and $F_2$ which depend on the first power of $(\Delta p)^2$ are being calculated to second order in the nucleon meson coupling using the cut-off theory with neglect of nucleon recoil. These results, and their comparison to experiment will be reported.

**D11. Nuclear Radius and Nuclear Forces.*** S. D. DRELL, *M.I.T.*—The difference between the "radius" of the nuclear matter distribution and the nuclear-force radius ($r_n \sim 1.45 A^{\frac{1}{3}} \times 10^{-13}$ cm) for $A \gtrsim 50$ is interpreted as a consequence of the finite range of nuclear forces. Assuming that the matter distribution coincides with the charge distribution as determined at Stanford ($r_e \sim 1.2 A^{\frac{1}{3}} \times 10^{-13}$ cm), we sum up the nuclear interactions of an incident nucleon for various proposed internucleon potentials, $V(r)$. We also evaluate induced spin, matter, and charge polarizations of the nuclear matter due to an impinging nucleon as a test of the convergence of these calculations. The aim here is to see what ranges and strengths of $V(r)$ are appropriate, say, to overcompensate the Coulomb barrier for protons at a distance $\sim r_n$. This approach is sensitive, in first order, only to the long-range behavior of the spin and charge independent portion of $V(r)$. It leads to the following conclusions. Either the neutron distribution extends at least 10 percent beyond the proton one or $V(r)$ must contain a sizeable amount of Wigner interaction with the range of a meson Compton wavelength. Such an interaction is not found in recent meson theoretically deduced $V(r)$. This result is insensitive to details of the tail of the charge distribution.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**D12. The Two-Nucleon Potential from the Cut-Off Yukawa Theory.** S. GARTENHAUS, *University of Illinois*.—Using the Yukawa theory with cut-off, the two-nucleon interaction is calculated up to fourth order in the coupling constant. The resulting potential at large distances ($\gtrsim 10^{-13}$ cm) is similar to the well-known potential with no cut-off.[1] At small distances, however, the tensor potential approaches zero, and the central potential is strongly repulsive. All details are completely determined by two parameters, the coupling constant and cut-off. The Schrödinger equation for the two-nucleon problem at low energies is solved using the Blatt-Kalos routine on the Illinois electronic computer, and values are obtained for the binding energy, the quadrupole moment, and the four $n$-$p$ scattering parameters. It is found that all experimental values are reproduced (to within 15 percent) with the same coupling constant and cut-off required to explain pion-nucleon scattering and photoproduction.[2]

[1] Taketani *et al.*, Progr. Theoret. Phys. **7**, 45 (1952); K. A. Brueckner and K. M. Watson, Phys. Rev. **92**, 1023 (1953); E. M. Henley and M. A. Ruderman, Phys. Rev. **92**, 1036 (1953).
[2] G. F. Chew, Phys. Rev. **95**, 1669 (1954).

**D13. On the Singlet $S$-State Nucleon-Nucleon Potential.*** R. B. RAPHAEL, *University of California, Berkeley*.—A knowledge of the singlet $S$-phase shift over only a limited energy region implies a corresponding limitation in the extent to which the $S$-state nuclear force may be determined from the scattering data. It will be shown, by means of a rapidly convergent approximation procedure suggested by Schwinger, that it is possible to know the value of the nuclear force at a discrete set of radial points only, whose number and distribution depend upon the energy range over which the $S$-phase shift is accurately represented. Thus the lowest approximation, corresponding to a knowledge of the $S$-phase shift between 0 and 10 Mev, produces a value at a single point, and is thus consistent with the shape-independent approximation. The next approximation, valid for scattering energies between 0 and 50 Mev, specifies the potential at three points within its range; when one uses the $S$-phase shifts appropriate to the usual potential shapes, the method reproduces these shapes with qualitative accuracy. When applied to the actual scattering data, the procedure produces an $S$-state potential having a repulsive core of radius $\sim 0.3 \times 10^{-13}$ cm. The effect on these results of alternate fits of the data and extensions of the method will be mentioned.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**D14. Anomalous $\tau$-Meson Decay.** TETSUO EGUCHI,* *Iowa State College*.—The possibility that a $\tau$ meson decays into two $\pi$ mesons and a photon is considered by perturbation calculation under the assumption that the $\tau$ meson ordinarily decays into three $\pi$ mesons via a virtual nucleon pair. Both processes are allowed if the $\tau$-meson field is a pseudoscalar with pseudoscalar coupling to the nucleon field. If the neutral $\tau$ meson exists, the decay $\tau^0 \to \pi^+ + \pi^- + \gamma$ would look like a $\theta^0$ event with a $Q$-value less than the normal value 214 Mev. The calculation shows that the probability of this decay with an apparent $Q$-value between 75 and 214 Mev is of the order of a few percent of that of the normal $\tau$-meson decay. The possibility of interpreting the anomalous $\theta^0$ events observed by Thompson[1] and others[2] in this manner will be discussed.

* Institute for Atomic Research, on leave from Kyushu University, Fukuoka, Japan.
[1] R. W. Thompson, Proceedings of the Fourth Annual Rochester Conference (1954).
[2] Van Lint, Anderson, Cowan, Leighton, and York, Phys. Rev. **94**, 1732 (1954).

**D15. The $\Lambda^0/\theta^0$ Ratio in Pb and C.** MARTIN M. BLOCK* AND ROBERT JASTROW, *Naval Research Laboratory*.—The yields of $\Lambda^0$ and $\theta^0$ particles have been calculated by Monte

Carlo techniques for 1.9-Bev $\pi^-$ mesons incident on Pb and C. Associated production ($\pi^-+N$(nucleon)$\rightarrow\Lambda^0+\theta^0$) is assumed and the histories of the unstable particles are followed via elastic scattering and the exchange reaction (1) $\theta^0+N\rightarrow\Lambda^0+\pi$. Reaction (1) increases the $\Lambda^0$ to $\theta^0$ ratio and is exothermic. The analogous reaction (2) $\Lambda^0+N\rightarrow\theta^0+2N$, which converts $\Lambda^0$'s to $\theta^0$'s, is effectively prohibited by its high threshold (~740 Mev), which lies above typical $\Lambda^0$ energies. Results will be reported for several assumptions on the relative probability of (1).

* On military leave of absence from Duke University, Durham, North Carolina.

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THURSDAY MORNING AT 10:00

NBS, East Building

(E. BURSTEIN presiding)

### *Invited Papers on Semiconductors*

**DA1. Polar Semiconductors.** W. W. SCANLON, *U. S. Naval Ordnance Laboratory.* (30 min.)

**DA2. Impact Ionization of Impurities in Germanium.** N. SCLAR, *U. S. Naval Research Laboratory.* (30 min.)

**DA3. Photoconductivity in Germanium.** W. W. TYLER, *General Electric Company.* (30 min.)

**DA4. Structure of Energy Bands in Semiconductors.** F. HERMAN, *RCA Laboratories.* (30 min.)

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THURSDAY AFTERNOON AT 2:00

Main Ballroom

(S. A. KORFF presiding)

### *Invited Papers on Photoproduction of Mesons and on Cosmic Rays*

**E1. The Photoproduction of Mesons in Hydrogen and Deuterium.** R. L. WALKER, *California Institute of Technology.* (30 min.)

**E2. Photopion Production from Nuclei.** K. M. CROWE, *Stanford University.* (30 min.)

**E3. Recent Results Concerning Hyperons and Heavy Mesons.** G. T. REYNOLDS, *Princeton University.* (30 min.)

**E4. *K*-Mesons and Hyperons in the Cosmic Radiation.** M. M. SHAPIRO, *Naval Research Laboratory.* (30 min.)

**E5. Cosmic-Ray Intensity near the North Magnetic Pole in 1954.** H. V. NEHER, *California institute of Technology.* (30 min.)

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THURSDAY AFTERNOON AT 2:00

Burgundy Room

(H. W. NEWSON presiding)

### *Neutron Physics, II*

**F1. Neutron Resonances in the Kilovolt Region: $Cl^{35}$, $Cl^{37}$, $K^{39}$, and $K^{41}$.*** L. A. TOLLER, J. R. PATTERSON, AND H. W. NEWSON, *Duke University.*—Neutron cross section curves have been measured by the transmission method between 2 and 200 kev for Cl and 2 to 120 kev for K. The strengths of the resonant spectra increase decidedly with atomic weight. Below 110 kev there are 9 resonance peaks in $K^{41}$, 9 in $K^{39}$, 6 in $Cl^{37}$, and 2 in $Cl^{35}$. However, the fractional loss of peaks is undoubtedly considerably greater for the lighter nuclides. Widths for some of the peaks have been estimated by the area method: $K^{41}$, 39(0.9); $K^{39}$, 43(0.3), 58(0.6), 68(0.8); $Cl^{35}$, 26.5(0.34); $Cl^{37}$, 8.8(0.09), 26.5(0.33), 47.4(0.20), 55.5(0.18), 65.0(0.18), and 94.2(0.80). The estimated value of the width (kev) is shown in parentheses next to the neutron energy of the peak. Compensating samples were used to cancel out any isotopic impurity greater than 5 percent; the frequency with which both isotopes have resonances at the same energy makes this precaution necessary. Peaks at 26.5, 141, and 190 kev are found in the cross section curves for both isotopes of Cl; and both K isotopes show peaks at 10, 23, 58, 96, and 110 kev. No plausible model is known which can account for the surprising frequency of this effect. The separated isotopes were prepared at Oak Ridge National Laboratory by C. P. Keim and his associates.

* This work was supported by the U. S. Atomic Energy Commission.

**F2. Total Neutron Cross Sections in the Kilovolt Region: $Zr^{91}$, $Zr^{92}$, and $Zr^{94}$.*** P. F. NICHOLS, R. G. SMITH, AND H. W. NEWSON, *Duke University.*—The total cross sections of $Zr^{90}$, $Zr^{92}$, and $Zr^{94}$ were measured as oxides by the transmission method over a neutron energy range from 5–140 kev. The neutron collimation-detection equipment has been previously reported.[1] The most prominent resonances in $Zr^{90}$ occur at 18(0.12) and 42(0.40) kev; in $Zr^{92}$ at 7(0.05) and 48(0.35) kev; and in $Zr^{94}$ at 20(0.11), 44(0.20), and 68(0.50) kev. The figures in parentheses are the estimated widths. Weaker resonances were found in each isotope. The resonances in $Zr^{90}$ are somewhat more prominent than in the others, but the apparent level spacings are about the same. Better resolution will be required to find the variation of level spacing near neutron number 50. The separated isotopes were prepared at Oak Ridge National Laboratory by C. P. Keim and his associates.

* This work was supported by the U. S. Atomic Energy Commission.
[1] J. H. Gibbons, Phys. Rev. **94**, 773 (1953).

**F3. Angular Distributions of Scattering of Moderate Energy Neutrons.** A. LANOSDORF, JR., AND R. O. LANE, *Argonne National Laboratory.*—Measurements of the angular distributions of the scattering of 0.1–1.5-Mev neutrons by various nuclei have been made at five laboratory angles, 22°, 54°, 92°, 112° and 144° with neutrons from the $Li^7(p,n)Be^7$ reaction: Five detectors, one at each angle, count simultaneously each with an efficiency of over 15 percent and a resolution of 1° to 5°. Detection is accomplished with oil-immersed $BF_3$ counters, and the response with energy in this range is flat to better than 10 percent when calibrated with a long counter. No discrimination is made between elastic and inelastic scattering. These data were obtained with an energy resolution of 50–100 kev. Though corrections for multiple scattering have not been made, they are minimized by the use of scatterers of at least 90 percent transmission. Differential scattering cross sections are calculated from integration of the angular distribution for carbon and its known smoothly varying cross sections in this range. Scattering cross sections obtained in a similar manner for the various elements measured are in good agreement with prior published values.[1]

[1] M. Walt and H. H. Barschall, Phys. Rev. **93**, 1062 (1954).

**F4. Elastic Scattering of 14.6-Mev Neutrons.** W. G. CROSS AND R. G. JARVIS, *Chalk River Laboratories.*—The differential cross sections for elastically-scattered 14.6-Mev neutrons have been measured at 25 angles between 10° and 125° for Mg and Bi, and over a smaller angular range for Ca, Cd, and Ta. A beam of neutrons from the $T(d,n)\alpha$ reaction is defined by counting only neutrons in coincidence with a collimated beam of $\alpha$ particles from the reaction.[1] Plastic scintillators are used for both the $\alpha$ and neutron counters. The neutron counter bias rejects neutrons of less than 11 Mev. Gamma rays from inelastic scattering are rejected because of their flight time. To reduce the background (mainly accidental coincidences) a copper bar shields the neutron counter from the source. The disk-shaped scatterers scatter five to 10 percent of the incident neutrons, the thicker scatterers being used for measurements at large scattering angles. Angular resolution is about ±3°. Minima in the angular distributions were found at the following angles (in degrees): Mg, 44±2, 113±5; Ca, 40±2, 75±2; Cd, 38±2, 85±5; Ta, 30±1; Bi, 27±1, 57±2.

[1] G. K. O'Neill, Phys. Rev. **95**, 1235 (1954).

**F5. Interaction of 3.7 Mev Neutrons with Al, S, Fe, and Cu.*** IRA L. MORGAN, *University of Texas.*—Neutrons of energy 3.7 Mev from the *d-d* reaction have been used to investigate the differential elastic scattering cross section of Al, S, Fe, and Cu, and gamma rays from inelastic scattering were also measured. A ring type geometry was employed with an overall resolution of 10° and scattering angles were varied from 10° to 150°. The detector and monitor were ZnS(Ag) buttons. Data for Fe and Al are in general agreement with earlier work.[1] Comparison of elastic scattering curves to certain theories will be presented. A NaI(Tl) crystal detector was placed at a scattering angle of 90°, and gamma rays produced by inelastic scattering were analyzed with a 20-channel analyzer. Gamma-ray energies were found to be generally consistent with earlier results,[2] obtained with 3.2 Mev neutrons. However, we find additional gamma rays of higher energy from Fe and Cu, and the intensities are markedly different. Further work on excitation functions for inelastic scattering is in progress.

* Assisted by the U. S. Atomic Energy Commission.
[1] W. D. Whitehead and S. C. Snowdon, Phys. Rev. **92**, 114 (1953).
[2] Scherrer, Allison, and Faust, Phys. Rev. **96**, 386 (1954).

**F6. Scattering of 4.4 Mev Neutrons by C, Ca, Fe, and Zr.*** J. B. WEDDELL AND B. JENNINGS, *Westinghouse Research Laboratories,* AND R. L. HELLENS, *Westinghouse Electric Corporation.*—The neutron spectra from the scattering of 4.4 Mev neutrons at 90° by carbon, calcium, and zirconium have been measured by the proton recoil photographic method. Previously reported results from iron[1] have been revised after additional measurements. The results permit location of energy levels in $Fe^{56}$ and Zr, and the estimation of differential elastic and inelastic scattering cross sections. Differential elastic cross sections at 90° are: C, 0.061±0.016 b/sterad; Ca, 0.053±0.013 b/sterad; Fe, 0.076±0.020 b/sterad; Zr, 0.096±0.024 b/sterad. Differential inelastic scattering cross sections for the first four excited states in $Fe^{56}$ are: (0.85 Mev), 0.036±0.010 b/sterad; (2.05 Mev), 0.021±0.007 b/sterad; (2.58 Mev), 0.012±0.006 b/sterad; (2.90 Mev), 0.020±0.013 b/sterad. Results for Zr are: (2.2 Mev), 0.009±0.004 b/sterad: (2.8 Mev, existence doubtful), 0.008±0.004 b/sterad. The results will be compared to predictions based on the theory of Feshbach, Porter, and Weisskopf.[2]

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Jennings, Weddell, and Hellens, Phys. Rev. **95**, 636 (1954).
[2] Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 448 (1954).

**F7. Gamma Radiation from the Interaction of 4.4-Mev Neutrons with Germanium and Tungsten.*** ROLF M. SINCLAIR, *Westinghouse Research Laboratories.*—Gamma radiation from samples of germanium and tungsten bombarded by 4.4±0.1-Mev neutrons has been observed. A single NaI(Tl) crystal, shielded from the direct neutron beam by a "heavy metal" wedge, was used as the detector. Germanium emits gamma rays of energy 0.52±0.02 (presumably annihilation radiation), 0.59±0.02, 0.82±0.02, 1.03±0.02, and 1.23±0.05 Mev. The 0.59 and 0.82-Mev gamma rays correspond in energy to transitions from known[1] excited states of $Ge^{74}$ and $Ge^{72}$, respectively. Tungsten emits two discrete gamma rays, of energy 0.63±0.02 and 0.75±0.02 Mev.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. Scharff-Goldhaber, Phys. Rev. **90**, 587 (1953), and references cited therein.

**F8. Analysis of Inelastic Neutron Scattering Data for Mn, Fe, and I.*** D. A. LIND AND J. J. VAN LOEF, *University of Wisconsin.*—Data on the inelastic scattering of neutrons by Fe, Mn and I have been reported.[1] The excitation curves reported have been analyzed using the transmission coefficients $T_l$ calculated for a square well potential of the form $V=42$ Mev $(1+i\xi)$ and $R=1.45\,A^{\frac{1}{3}}\times10^{-13}$ cm with the theory developed by Hauser and Feshbach.[2] It is impossible to determine spin assignments unambiguously from the data. A $7/2^+$ assignment to the 128 kev level in $Mn^{55}$ gives the best fit. The $Fe^{56}$ excitation curve is fit best by the assignment of 2+ but 1+ or 1− would give equally good fits. These are ruled out by the angular distribution of the 850-kev gamma

radiation. The distribution is given by $W(\theta)=1+a_2P_2(\theta)+a_4P_4(\theta)$ where $a_2=0.38\pm0.10$ $a_4=0.16\pm0.05$. The best fit of these data with theory is obtained for a $\zeta=0.2$. No unique spin assignment can be made on the basis of the excitation curves for the 62, 208, 435, and 632-kev levels of I. A comparison of the total inelastic scattering cross section for $I^{127}$ with the capture cross section calculated on the basis of theory indicates that a value of $\zeta=0.2$ is needed.

* Research was supported by the U. S. Atomic Energy Commission and he Wisconsin Alumni Research Foundation.
[1] Van Loef and Lind, Bull. Am. Phys. Soc. 29, No. 7, B5 (1954).
[2] Hauser and Feshbach, Phys. Rev. 87, 366 (1952).

**F9. Fast Neutron Reactions in KI(Tl) Crystals.** MARY JEAN SCOTT AND RALPH E. SEGEL, *Johns Hopkins University.*—The heavy charged particle spectrum resulting from the bombardment of KI(Tl) with neutrons has been investigated. Thin (~15 mil) KI(Tl) crystals were mounted on photomultiplier tubes and the pulse-height spectra recorded in a 99 channel analyzer. For fast monoenergetic neutrons of energy less than 3.5 Mev, a single peak was observed in the spectrum. The pulse height varied correctly with neutron energy if the group is identified with the reaction $K^{39}(n,p)A^{39}$. At higher neutron energies, a broad peak appears in the spectrum at lower pulse height. This broad peak has been tentatively ascribed to transitions to two excited states of $A^{39*}$ which have been previously reported at 1.33 and 1.68 Mev.[1] The potentialities of KI(Tl) crystals for counting neutrons in various energy ranges will be discussed.

[1] Nussbaum, Van Lieshout, and Wapstra, Phys. Rev. 92, 207(L) (1953).

**F10. Secondaries from High Energy Neutron Interactions with Tungsten.*** R. W. WANIEK, L. GARRIDO, R. GOLOSKIE, AND E. G. SILVER,† *Harvard University.*—With the technique previously described,[1,2] Tungsten wires of 13 microns diameter embedded in Ilford G5 emulsions were exposed to neutrons of 40, 70, and 110 Mev maximum energy. The neutron spectra were hardened by inserting one mean free path of $CH_2$ at the respective energies. The spectra of the ejected protons and alpha particles are all peaked at energies far below the conventional Coulomb barrier. There is some evidence for the presence of a few peaks in the proton spectra. The angular distributions of the secondaries with energies below 10 Mev is anisotropic. Some evidence for localized interactions leading to the emission of nuclear fragments is provided by a few instances. The process could be compatible with the assumption of an asymmetric fission-like mechanism excited by specialized oscillations of the nucleus.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Oak Ridge School of Reactor Technology.
[1] Waniek, Fox, Garrido, and Silver, Bull. Am. Phys. Soc. 30, No. 1, 9 (1955).
[2] E. G. Silver and R. W. Waniek, Rev. Sci. Instr. 25, 119 (1954).

***Invited Paper***

**F11. Widths and Spacings of Nuclear Energy Levels.** D. J. HUGHES, *Brookhaven National Laboratory.* (30 min.)

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THURSDAY AFTERNOON AT 2:00

Exhibit Hall I

(E. M. PURCELL presiding)

## *Radio-Frequency Spectroscopy, II; Optical and Atmospheric Physics*

**FA1. Interpretation of the Knight Shift in Metallic Sodium.** T. KJELDAAS, JR., *Westinghouse Research Laboratories,* AND W. KOHN, *Carnegie Institute of Technology.*—The Knight shift of the nuclear resonance frequency in metals is due to the interaction of the magnetic moments of nuclei and those of the conduction electrons.[1] The fractional shift is proportional to the product of $\chi_p$, the electron spin susceptibility, and $P_F$, the average probability density of conduction electrons at the nucleus.[1] A calculation of $P_F$ for metallic sodium has been carried out, similar to one recently reported for lithium.[2] The resulting value of $P_F=0.61\ a_0^{-3}$ is in good agreement with the result of reference one, and when combined with the experimental value of the shift,[3] yields $\chi_p=(0.86\pm0.03)\times10^{-6}$ cgs mass units, in excellent agreement with the theoretical value of Pines.[4] The volume dependence of $P_F$ was found to be small; this would seem to rule out the possibility that the observed[5] large low-temperature anomaly is due to a change of $P_F$ in a phase transformation.

[1] Townes, Herring, and Knight, Phys. Rev. 77, 852 (1950).
[2] W. Kohn, Phys. Rev. 96, 590 (1954).
[3] H. S. Guttowsky and B. R. McGarvey, J. Chem. Phys. 20, 1472 (1952).
[4] D. Pines, Phys. Rev. 95, 1090 (1954).
[5] W. D. Knight, Phys. Rev. 96, 861 (1954).

**FA2. Calculation of a Spin Resonance Equation.** J. I. KAPLAN, *United States Naval Research Laboratory.*—A method is given for calculating the spin resonance equations under the following conditions: (1) the rf field may have any magnitude relative to the constant magnetic field; (2) the frequency of the rf field is monochromatic; (3) the system is defined by one relaxation time; (4) the rf intensity is assumed constant over the sample but the constant field may be inhomogeneous.

**FA3. Theory of Magnetic Resonance Saturation.*** E. P. GROSS, *Syracuse University.*—We use equations which are generalizations of the Karplus and Schwinger type to study saturation in magnetic resonance absorption. Spin-spin interactions are in the Liouville term, while spin lattice interactions are represented by the stochastic term. For gases, the magnetization satisfies equations differing from those of Bloch in the transverse components tend to relax to the instantaneous value of applied field. When spin-spin interactions are important, a solution is obtained for line width small compared to the Larmor frequency. The solution agrees with Redfield's[1] postulate that the density matrix is canonical in the rotating coordinate system for circularly polarized rf fields. The defects of Bloch's equations are traced to using perturbation theory in analyzing the statistical behavior of a system in weak interaction with a reservoir. We develop a generalization of the Weisskopf-Wigner approach and find generalizations of the equations used in the foregoing. The restriction to processes near equilibrium made in irreversible thermodynamics is artificial. We require that the line width due to reservoir interaction be small compared to the separation of combining

system levels; the spin system can deviate arbitrarily from equilibrium.

* Supported by Office of Scientific Research, U. S. Air Force.
[1] A. G. Redfield, Bull. Am. Phys. Soc. **30**, No. 1, 43 (1955), abstract R4.

**FA4. Indirect Exchange Coupling of Nuclear Moments by Electrons in Semiconductors and Insulators.** P. W. ANDERSON, *Bell Telephone Laboratories.*—The indirect exchange mechanism for nuclear moments proposed by Ramsey[1] for molecules and Kittel and Ruderman[2] for metals has been worked out for simple models of semiconductors and insulators. The mechanism nvolves the virtual excitation of triplet states by the hyperfine interaction. The result is rather similar to, but in some ways more general than, that of Bloembergen.[3] It appears from our results that even for the case of metals considered by Ruderman and Kittel, as well as for the present case in particular, the electronic states of interest have rather large energies relative to the Fermi level. This has two interesting physical consequences: (a) Coulomb interaction effects such as exciton formation are not important. (b) The accuracy of all such calculations is severely limited by the fact that effective mass approximation as well as constancy of the hyperfine interaction constants cannot be expected to hold well over such large energy ranges. Within the rather wide margin for error allowed by (b), comparison with the experimental results of Shulman, Mays, and McCall[4] for InSb and GaSb is satisfactory.

[1] N. F. Ramsey, Phys. Rev. **91**, 303 (1953).
[2] M. A. Ruderman and C. Kittel, Phys. Rev. **96**, 99 (1953).
[3] N. Bloembergen, Bull. Am. Phys. Soc. **30**, 44 (1955) (to be published).
[4] Shulman, Mays, and McCall, Bull. Am. Phys. Soc. **30**, 43 (1955), abstracts R2 and R3.

**FA5. Quantum Theory of Dielectric Relaxation.*** JOEL L. LEBOWITZ AND E. P. GROSS, *Syracuse University.*—Dielectric relaxation in compressed gases has been studied[1] using a classical theory involving impacts of duration that are short compared to the resonant period, the period of the applied field, and time between collisions. The present work deals with the unified treatment of the discrete rotational lines at low pressures, the continuous absorption determined by quantum and inertial effects at intermediate pressures, and the Debye absorption at high pressures. This is accomplished with the impulsive model by using the Wigner distribution function to construct quantum kinetic equations from the classical theory. Our quantum characterization of impulsive collisions is that the diagonal elements of the density matrix in the position representation are unchanged by collisions. Analysis of the resulting absorption justifies using classical theory to estimate inertial effects at higher pressures, and confirms the connection between collision frequency and Debye relaxation time noted earlier.

* Supported by Office of Scientific Research, U. S. Air Force.
[1] E. P. Gross, Phys. Rev. **97**, 395 (1955); Bull. Am. Phys. Soc. **30**, No. 1 (1955), abstract TA14.

**FA6. An Application of the Photomultiplier to the Interference Spectroscope.*** JOSEPH G. HIRSCHBERG, *University of Wisconsin.*—Following ideas developed especially by P. Jacquinot[1] and in this laboratory, the liquid-air cooled photomultiplier is applied to the study of fine details in complex spectrum lines with the Fabry-Perot interferometer. Sweeping is accomplished alternatively by varying air pressure or by actually varying the spacer distance mechanically. The interferometer is coupled with a 21-foot concave grating in a double-pass modified Wadsworth mounting[2] and the two are swept in synchronism. The system is applied to the spectrum of helium.

* Supported by the Wisconsin Alumni Research Foundation and by the Office of Ordnance Research.
[1] Private communication.
[2] E. Hulthén and E. Lind, Arkiv Fysik **2**, 253 (1950).

**FA7. Isotope Shift Nonlinearities in the Spectrum of Cadmium.** W. M. CLOUD, *University of Wisconsin.**—Measurements of spectrograms of cadmium, taken with an atomic beam source (constructed under the direction of Dr. Arroe) and a Fabry-Perot interference spectrograph (with dielectric coatings supplied by Professor Jacquinot) yield tentative results for the transition $_{48}$Cd II, $\sigma$22640, ($4d^{10}5p^3P_{3/2}^0 - 4d^9 5s^2\,{}^2D_{5/2}$) in fair, but not complete, agreement with other work[1-4] on the same line, as shown in the following table of shifts in mK (where $S$ refers to the strongest component):

| Isotope | 106 | 108 | 111$S$ | 110 | 113$S$ | 112 | 114 | 116 |
|---|---|---|---|---|---|---|---|---|
| $S$ W[1] | | | | 0 | | 54 | 105 | |
| $M$[2] | −106 | −56 | −20 | 0 | 35 | 55 | 109 | 147 |
| $H$ K $R$[3] | | | | 0.0 | | 53.3 | 101.2 | 135.6 |
| $W$ S[4] | −112.2 | −51.2 | −15.2 | 0.0 | 39.4 | 53.1 | 99.9 | 135.6 |
| This work | −113.2 | −52.1 | −18.9 | 0.0 | 35.2 | 53.5 | 98.4 | 134.0 |

* Supported by Office of Naval Research and Office of Ordinance Research.
[1] H. Schüler and H. Westmeyer, Z. Physik **82**, 685 (1933).
[2] K. Murakawa, Phys. Rev. **93**, 1232 (1954).
[3] Hindmarsh, Kuhn, and Ramsen, Proc. Phys. Soc. (London) **A67**, 478 (1954).
[4] E. C. Woodward and D. R. Speck, Phys. Rev. **96**, 529(A) (1954); see E. C. Woodward, Phys. Rev. **93**, 948(A) (1954).

**FA8. Isotope Shift in the Ionized Spectrum of Carbon.*†** C. R. BURNETT, *Pennsylvania State University.*—The isotope shift between $C^{12}$ and $C^{13}$ in the $2s2p^3\,{}^3P - 2p^3\,{}^3D$ transitions of ionized carbon has been resolved using a Fabry-Perot interferometer. Preliminary measurements are 0.94 K for λ2512 $2s2p^3\,{}^3P_{3/2} - 2p^3\,{}^3D_{3/2}$ and 0.89 K for λ2509 $2s2p^3\,{}^3P_{1/2} - 2p^3\,{}^3D_{3/2}$ with the $C^{13}$ component at higher frequency in both cases. The calculated normal mass effect is 0.14 K. The difference in shift for the two lines appears to be real, as is also the case for the $2s2p^3\,{}^3S - 2s^23p^3P$ transitions.[1] Excitation of the enriched sample of $C^{13}$ consisted of a mild condensed discharge in a hollow cathode source cooled with liquid nitrogen. It is to be noted that the above configurations differ in the number of $2s$ electrons and should thus be sensitive to nuclear volume effects. It is planned to continue this study using an enriched sample of $C^{14}$.

* This study was initially supported at South Dakota State College by Engineering and Science Research funds.
† This project is now supported by a grant from the Research Corporation.
[1] C. R. Burnett, Phys. Rev. **80**, 494 (1950).

**FA9. Mesonic X-Rays from Capture of Cosmic Ray Mu Mesons in a Chemical Compound.** A. FAFARMAN AND M. H. SHAMOS, *New York University.*—Measurements of the x-rays emitted by mesonic carbon and oxygen atoms have been made, using a different experimental arrangement than that reported for Pb. A tank (~4 liters) of liquid scintillator, dioxane, $C_4O_2H_8$, (plus 10 g/l of p-terphenyl) served as the absorber and as the detector for the stopping of cosmic ray mu mesons. The mesons were identified by the method of delayed coincidences ($\mu-\beta$ event). The mesonic x-rays from the dioxane were detected by a coincidence scintillation spectrometer ($\gamma$ pulse), which included a 4 in. diam × ½ in. thick NaI crystal together with a 5 in. diam 6364 photomultiplier. Those $\gamma$ pulses in coincidence with the $\mu$ of $\mu-\beta$ events ($\mu\gamma-\beta$ events) were lengthened and their pulse height recorded on a recording milliammeter. The time distribution of the delayed coincidences ($\mu\gamma-\beta$ events) was recorded by a 4-channel delay discriminator over the delay interval 0.5 to 8.0 μsec. It was possible to study the mesonic x-rays with essentially no background, and with no contribution from nuclear absorption gamma radiation nor from (decay beta particle) bremsstrahlung. The measured $2p-1s$ transition energies of 82 kev and 145 kev for carbon and oxygen respectively agree with the simple Bohr orbit calculations. The observed ratio of captures by oxygen and carbon (0.33±0.04) does not agree with the $Z$ dependence predicted by Fermi and Teller for mesonic atom formation by this chemical compound (0.67), nor with the simple stopping power calculation (0.50).

**FA10. Dispersion Electrons and Refractive Index in the Soft X-Ray Region.*** D. E. BEDO AND D. H. TOMBOULIAN, *Cornell University.*—Recent investigations indicate that the continuous soft x-ray spectrum emitted by electrons accelerated in a synchrotron[1] may serve as a source of known spectral distribution. In conjunction with expressions[2] for the reflecting power of a glass grating, the spectrum of such a source was utilized to evaluate the refractive index of the grating material. The index is found to increase from 0.915 at 180 A to 0.950 at 380 A. The real decrement of the refractive index has the form $A\lambda^2Q$. If the material of the grating be regarded to possess the $SiO_2$ structure, and if $Q$ may be assumed to represent the number of dispersion electrons per $SiO_2$ molecule, then computed values of $Q$ drop from almost 24 at 180 A to 3 at 380 A. This suggests that at the shorter wavelength all $L$ and $M$ shell electrons of the molecule participate in the dispersion process, while at the higher wavelength only the $M$ electrons are effective.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] P. L. Hartman and D. H. Tomboulian, Phys. Rev. 91, 1577 (1953).
[2] G. C. Sprague (to be published).

**FA11. Preliminary Experiments on X-Ray Microscopy by Reconstructed Wave Fronts.*** HUSSEIN M. A. EL-SUM AND ALBERT V. BAEZ, *University of Redlands.*—The point-focus x-ray tube at the University of Redlands has been used for making shadow projection microradiographs of biological and metallurgical objects. Depending on the geometrical arrangement of source, object, and film, the shadow may lose its sharpness and exhibit a diffraction pattern of the object. Using continuous radiation from Al, Ag, and Au targets, holograms of simple objects like single wire, fine grid and sharp edge were made, showing up to three fringes. The appearance of the diffraction fringes in these holograms differs from those using visible radiation, due to the absorption of the x-rays by the diffracting object. Any possible discrepancy between our results and our formula connecting source size, number of registered fringes, film resolution, wavelength, and geometrical parameters can be attributed to the fact that nonmonochromatic x-radiation was used. The reconstruction of such x-ray holograms using visible radiation will be discussed.

* Supported in part by grants-in-aid from the Research Corporation, the Office of Naval Research and the American Cancer Society upon recommendation of the Committee on growth of the National Research Council.

**FA12. Atmospheric Attenuation of Solar Millimeter Wave Radiation.** H. H. THEISSING AND P. J. CAPLAN.—The instrumentation consisted of a 60 in. searchlight parabola, $f=25.5$ in., in the focus of which was a thermal detector with a sensitive area about 8 mm in diameter, which approximately equals the geometric image of the sun. A set of black filters suppressed the powerful visible and near infrared solar intensity. A filter method was chosen to determine the intensity distribution of the millimeter spectrum. These spectral measurements, which will be described in a separate publication, showed a peak at about 1 mm. For this spectrum the atmospheric attenuation $\alpha$ (per km per percent $H_2O$ vapor) was measured by observing the solar signal during greatly varying humidity conditions At the same time, the percentage water concentration (c) from ground level up to 20 000 feet was known from balloon data, which made it possible to treat the upright path as if it were a horizontal path. If $\bar{c}$ is the average water vapor concentration in the sun's total atmospheric path $\bar{d}$—varying with various elevation angles—the observed signal $S$ will be proportional to $\exp(-\alpha\bar{c}\bar{d})$. Plotting, therefore, $\log S$ *vs* $\bar{c}\bar{d}$ actually furnishes a plot of $-\alpha\bar{c}\bar{d}$ *vs* $\bar{c}\bar{d}$, which should be a straight line with the slope $-\alpha$. The experimental value of $\alpha$ obtained in this way was compared with atmospheric attenuation data computed by T. F. Rogers.*

* Atmospheric millimeter absorption data computed and presented at the Navy Millimeter Wave Conference in Washington, 1953, by T. F. Rogers, Air Force Cambridge Research Center (unpublished).

**FA13. A Comparison of Observed Drop-Size Distributions in Clouds and Rain with Proposed Analytical Expressions.*** SHEPARD BARTNOFF, *Tufts College.*—The two functions, $y(x)=(m\ln 2)x^{m-1}\exp(-x^m\ln 2)$ derived from Best's[1] formula and $y_n(x)=AX^{(a/b)-1}(2-x^{1/b})^a$ developed by Atlas and Bartnoff,[2] are compared and are found to be nearly identical with respect to distribution parameters obtained from natural clouds and rain. The moments $\mu_2$, $\mu_3$, and $\mu_4$ computed from individual distributions are found to be highly correlated with similar moments obtained from the family of curves described by Best's function, indicating that natural distributions in clouds and rain can be satisfactorily represented analytically.

* This work is supported by a contract with the Air Force Cambridge Research Center.
[1] A. C. Best, Quart. J. Roy. Meteorol. Soc. 76, 16–36 (January, 1950).
[2] D. Atlas and S. Bartnoff, J. Meteorol. 10, 143–148 (1953).

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## THURSDAY AFTERNOON AT 2:00

NBS, East Building

(J. BARDEEN presiding)

### *Semiconductors, I*

**G1. Ionization and Solubility of Impurities in Semiconductors.*** C. S. FULLER AND HOWARD REISS, *Bell Telephone Laboratories.*—Impure semiconductors like Ge and Si behave like dilute aqueous solutions in that, in both instances, the equilibrium solubilities of ionic impurities in them depends on the ionization of the media as well as upon the ionization of other solutes present.[1] Using simple mass action law arguments, relations have been developed[2] for the specific case of the equilibrium solubility of the donor Li in silicon as a function of known dopings of the acceptor boron at different temperatures. These relations have been tested experimentally by determining the changes in resistivity of a series of specimens of $p$-type silicon containing up to $5.6\times10^{18}$ boron/cm$^3$. The observed solubilities are found to be in satisfactory agreement with theory thus validating the empirical mobilities as well as the essential correctness of the theory. The maximum in the solubility curve of Li in undoped Si as a function of temperature previously observed[3] can be explained by the increase in intrinsic electron concentration with temperature.

* J. Chem. Phys. (to be published).
[1] H. Reiss, J. Chem. Phys. 21, 1209 (1953).
[2] H. Reiss and C. S. Fuller, Phys. Rev. 97, 559 (1955).
[3] C. S. Fuller and J. A. Ditzenberger, Phys. Rev. 91, 193 (1953).

**G2. Electron Capture Probability of the Upper Copper Acceptor Level.** J. F. BATTEY AND R. M. BAUM, *Sylvania Electric Products.*—Copper has been diffused into originally $n$-type germanium to such an extent that the upper acceptor levels introduced by the copper atoms are approximately half

populated.[1] It has been shown previously that the upper copper levels in germanium act as recombination traps.[2] Using approximations appropriate to the circumstances, the minority carrier lifetime[3] is expected to be inversely proportional to the electron capture probability of the levels over the temperature range investigated. It is found in contrast to previously reported measurements[4] on samples with unknown recombination level structures that the lifetime decreases exponentially with increasing temperature. A suggested interpretation is that only electrons of energy greater than 0.22 ev above the bottom of the conduction band can enter the upper copper acceptor levels.

[1] J. F. Battey and R. M. Baum, Phys. Rev. **94**, 1393 (1954).
[2] J. A. Burton *et al.*, J. Phys. Chem. **57**, 853 (1953).
[3] W. Shockley and W. T. Read, Jr., Phys. Rev. **87**, 835 (1952).
[4] R. N. Hall, Phys. Rev. **87**, 387 (1952).

**G3. Two-Carrier Model of *p*-type Germanium at 77°K.** E. N. ADAMS, R. E. DAVIS, AND COLMAN GOLDBERG, *Westinghouse Research Laboratories.*—The conduction mobility at liquid air temperature was studied for samples of *p*-type germanium ranging in impurity content from about $10^{13}$ to $4\times10^{14}$. Appreciable dependence of the mobility on impurity content was found even for samples of impurity content less than $10^{14}$. The field dependence of the Hall constant and magnetoresistance was measured for each sample. An analysis of these data suggest that for samples with impurity concentrations below $10^{14}$ the dependence of the mobility on impurity content originates in impurity scattering of fast holes. Preliminary interpretation of the data on a two-carrier model indicates that the parameters which give the best fit are somewhat different from those found at higher temperatures.[1]

[1] Herman, Willardson, and Beer, Phys. Rev. **96**, 1512 (1954).

**G4. Mobility of Holes in Germanium-Silicon Alloys.** A. LEVITAS, *Sylvania Electric Products.*—Hall and resistivity measurements have been performed on nine samples of *p*-type germanium-silicon alloys ranging in composition from 100 percent germanium to 100 percent silicon. The measurements were performed in a temperature range extending from 80°K to 390°K. Brooks[1] has predicted that alloy scattering will have a significant effect on the mobilities of the alloys, and the measured mobilities are consistent with this prediction. At reduced temperatures the mobilities depart from a power law in temperature in a manner which suggests the operation of a mechanism which becomes increasingly important as the composition of the alloy is changed from 100 percent of one constituent toward a 50 percent alloy. This mechanism is presumably alloy scattering. The behavior is masked to some extent by impurity scattering, and an attempt will be made to correct for this effect.

[1] H. Brooks (private communication).

**G5. Modulation of Schottky Emission from Metal Point Contacts to Germanium.** G. WALLIS AND J. F. BATTEY, *Sylvania Electric Products.*—A new confirmation has been found for the Schottky emission diode theory of reverse current by Simpson and Armstrong.[1] The surface barrier, $\phi$, of germanium diodes (15 to 25 ohm-cm, *n*-type with pulsed tungsten whiskers) was modulated by the ambient cycle dry oxygen, wet oxygen, ozone.[2] Changes in $\phi$ on the free surface were monitored by contact potential measurements. Simultaneously measured changes in pulsed reverse diode current, $i$, were consistent with theory, if it was assumed that $\phi$ under the whisker changed in the same direction as on the free surface. Theory[1] predicts the observed voltage dependence of the current changes with ambient, $\Delta i/i \simeq -A\Delta\phi(1-B/V^{\frac{1}{2}})$, where $A$ and $B$ are positive constants for a given contact, $V$ is the reverse bias, and $\Delta i$ and $\Delta\phi$ are the changes with ambient in $i$ and $\phi$. Such analysis of high voltage diodes shows $\phi$ to be between 0.60 and 0.65 ev, the field due to the holes at the contact to be about $5\times10^5$ volts/cm, the field due to $V$ about $10^4V$ volts/cm.

[1] J. H. Simpson and H. L. Armstrong, J. Appl. Phys. **24**, 25 (1953).
[2] W. H. Brattain and J. Bardeen, Bell System Tech. J. **32**, 1 (1953).

**G6. Forward Characteristic of Germanium Point Contact Rectifiers.** M. CUTLER, *Hughes Aircraft Company.*—A quantitative discussion of the forward characteristic is given for point contact rectifiers. It is based on the combined solution of the emission equations for the barrier[1] and the diffusion equations for the bulk region.[2] It shows that the theoretical value of $d\ln I/dV$ in the exponential region is nearly $q/kT$, and that the experimental slopes which are a fraction of this value cannot be the result of the spreading voltage. Recombination of injected carriers has little effect except at large currents beyond the exponential region. Relations are derived for the limit of very large currents, which show that gamma approaches a value smaller than $(1+b)^{-1}$, the hole concentration at the contact approaches a maximum value proportional to the equilibrium concentration of holes at the surface, and the spreading voltage becomes a linear function of the current.

[1] M. Cutler, Phys. Rev. **96**, 255 (1954).
[2] J. A. Swanson, J. Appl. Phys. **25**, 314 (1954).

**G7. Silicon Conductivity Modulated Diffused $p-n$ Junction Rectifier.** M. B. PRINCE, *Bell Telephone Laboratories.*—Impurity diffused type silicon rectifiers[1] can now be made incorporating the feature of conductivity modulation. These devices, using areas of 0.1 cm², conduct more than 35 amperes at 1 volt in the forward direction. It will be shown that complete conductivity modulation of the device leads to a constant voltage drop independent of the forward current. Thus the effective series resistance of the device is about 0.005 ohm for 0.1 cm² wafers.

[1] G. L. Pearson and C. S. Fuller, Proc. Inst. Radio Engrs. **42**, No. 4 (1954).

**G8. Sensitization of Photoconductivity in PbSe.** JAMES N. HUMPHREY, *U. S. Naval Ordnance Laboratory, and University of Maryland.*—The sensitization of PbSe films has been investigated using oxygen, sulfur, selenium, and the halogens as sensitizers. Each sensitizer acts as an acceptor impurity, converting *n*-type films to *p*-type, at the condition of maximum resistance. At −195°C each sensitizer produces photoconductivity with minimum time constants of about 15 microseconds. At 25°C measurable sensitivity ($\tau\sim1$ microsecond) results only if oxygen is introduced, alone or with another sensitizer. It is believed that each sensitizer produces surface states giving the resistance maximum and change of carrier sign. At −195°C the observed 15 microsecond time constant is identified with that of recombination centers which are present independent of sensitization. Any sensitizer able to raise the dark resistance will produce photoconductivity with this $\tau$. At 25°C the recombination center time constant is shorter, probably $10^{-8}$ second or less. This is too short to yield measurable photoconductivity. Oxygen, however, in addition to producing surface states, enters the lattice. The resulting ions represent traps with very short capture times and longer decay times (~1 microsecond at 25°C). These traps compete with the recombination centers, capturing optically excited electrons and delaying recombination. The resulting free holes produce photoconductivity having a $\tau\sim1$ microsecond.

**G9. Silicon Analysis for Boron by Thermal Neutrons.** E. G. K. SCHWARZ, *Signal Corps Engineering Laboratories.*—Simultaneous alpha counting under thermal neutron irradiation offers an extremely sensitive method to analyze ultra pure silicon for boron impurities. Alpha-counting rates were calculated in terms of boron concentration and thermal neu-

tron flux for a thin alpha-saturated flat silicon sample. The most suitable technique for this analysis is scintillation counting by means of a silver activated zinc-sulfide screen in connection with a photomultiplier tube. It was estimated that the sensitivity of spectrochemical analysis can be surpassed by more than four orders of ten when the highest available thermal neutron fluxes are utilized. Interferences originating from gamma background radiation and from $Li^6$ traces which may be present in the neighborhood of the detector are discussed.

**G10. Hall Effect and Conductivity of InSb.** H. J. HROSTOWSKI, F. J. MORIN, T. H. GEBALLE, AND G. H. WHEATLEY, *Bell Telephone Laboratories.*—High purity InSb has been prepared by zone refining.[1] Single crystal samples with total impurity concentration of $10^{16}$ $cm^{-3}$ have electron and hole mobilities much higher than previously reported.[2] Hall mobilities at 78°K are $3.7\times10^5$ $cm^2$/volt sec for electrons, and approximately $10^4$ $cm^2$/volt sec for holes. Impurity scattering contributes appreciably to the observed electron mobility up to 300°K. Lattice scattering mobilities of both electrons and holes have temperature dependence different from $T^{-\frac{3}{2}}$. With an effective electron mass of 0.015 $m$ the electron lattice scattering mobility is proportional to $T^{-1.7}$. Determination of Hall mobility for positive holes is complicated by the variation of the Hall coefficient with magnetic field[3] in $p$-type material. Estimation of the ratio of Hall to conductivity mobility indicates nonspherical energy surfaces in the valence band. Low temperature measurements show no ionization of donors. In $p$-type InSb below 10°K impurity band conduction is observed.[4] Above 10°K acceptors are ionized. The activation energy is $7\pm1\times10^{-3}$ ev. An effective hold mass between 0.1 m and 0.25 m is required to fit the experimental data.

[1] W. G. Pfann, Trans. Am. Inst. Mining Met. Engrs. 194, 747 (1952).
[2] O. Madelung and H. Weiss, Z. Naturforsch. 9a, 527 (1954).
[3] Harman, Willardson, and Beer, Phys. Rev. 95, 699 (1954).
[4] C. S. Hung and J. R. Gliessman, Phys. Rev. 96, 1226 (1954).

**G11. Effects of Hydrostatic Pressure on the Conductivity of InSb.** ROBERT W. KEYES, *Westinghouse Research Laboratories.*—The effect of high hydrostatic pressures on the electrical conductivity of $n$ and $p$ type specimens of InSb has been measured in the temperature range −80° to +270°C. Pressures up to 12 000 kg/$cm^2$ were employed. The energy gap was found to increase at a rate $1.5\times10^{-6}$ ev/atmos, a value slightly less than that found by Long and Miller.[1] The variation of the carrier mobilities with pressure is obtained from the changes in conductivity in the exhaustion range. The mobility of the electrons decreases with increasing pressure and is approximately inversely proportional to the energy gap. The mobility of the holes is almost independent of pressure. A simple picture of the band shapes which allows these mobility effects to be understood and which is in accord with other data on InSb will be suggested.

[1] D. Long and P. H. Miller, Jr., Bull. Am. Phys. Soc. 30 No. 1, 53 (1955), abstract V8.

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## THURSDAY AFTERNOON AT 2:00

## Exhibit Hall II

## (R. PEPINSKY presiding)

### *Ferroelectricity and Ferromagnetism*

**GA1. Guanidine Aluminum Sulfate Hexahydrate—A New Ferroelectric Material.** A. N. HOLDEN, B. T. MATTHIAS, W. J. MERZ, AND J. P. REMEIKA, *Bell Telephone Laboratories.*—Guanidine aluminum sulfate hexahydrate[1] is ferroelectric over a large range of temperatures including room temperature. It is the parent of a family of materials in which the aluminum cation and the sulfate anion can be replaced by the anions and trivalent cations which form alums, for example $Ga^{3+}$, $Cr^{3+}$, and $SeO_4^{--}$. Replacement of guanidine has so far proved impossible. The material is trigonal, with perfect cleavage in the basal plane; the trigonal axis is the ferroelectric direction. The space group is $C_{3v}(2)$—$P31m$, and the unit cell contains three molecules. It can be readily grown from water solution by standard techniques.[2]

[1] Ferraboschi, Cambridge Phil. Soc. 14, V, 473 (1908).
[2] Holden, Discussion Faraday Soc. No. 5, 312 (1949).

**GA2. Electrical Properties of Guanidine Aluminum Sulfate Hexahydrate (G.A.S.H.) and Some Isomorphs.** W. J. MERZ, J. P. REMEIKA, A. N. HOLDEN, AND B. T. MATTHIAS, *Bell Telephone Laboratories.*—At room temperature very symmetrical and square hysteresis loops can be obtained with G.A.S.H. The spontaneous polarization is about $P_s=0.35$ microcoulomb/$cm^2$. G.A.S.H. is thus a weak ferroelectric crystal similar to rochelle salt and in contrast to $BaTiO_3$. The coercive field strength is strongly frequency dependent; 60 cycles per sec $E_c\cong1500$ volts per cm. The small signal dielectric constant is only about 15 along the ferroelectric axis and about 5 perpendicular to it. Very little change in the dielectric constant is observed when the crystal is heated. Above 100°C, where the crystal starts to lose water of crystallization, no reproducible results can be obtained, and hence no determination of the Curie point could be made. The polarization $P_s$ decreases linearly with increasing temperature suggesting a Curie temperature of about 200°C–300°C. The coercive field $E_c$ increases rapidly at low temperatures. The ferroelectric properties of the isomorphs are very similar to those of G.A.S.H. If crystals are subjected to square electrical pulses the switching time $t_s$ becomes shorter the higher the applied field, as in the case of $BaTiO_3$,[1] though the switching time of G.A.S.H. is longer.

[1] W. J. Merz, Phys. Rev. 95, 690 (1954).

**GA3. Oxygen Parameters of the $FeFe_{(2-x)}Cr_xO_4$ Spinel System.*** H. J. YEARIAN AND W. D. DERBYSHIRE, *Purdue University.*—Oxygen parameter measurements of powdered samples of spinels of the $FeFe_{(2-x)}Cr_xO_4$, $0\leq x\leq2$, system have been made at room temperature by x-ray diffraction intensity methods. The value of the parameter, which measures the space available to the cation in a tetrahedral position, was found to vary monotonically from $0.378\pm0.002$ at $x=0$

to $0.387 \pm 0.002$ at $x=2$. The samples were prepared according to the process described by Yearian, Kortright and Langenheim.[1] They interpreted the lattice parameter measurements of these spinels as indicating that: from $x=0$ to $x=0.3$ the structure is completely inverse; from $x=1.28$ to $x=2.0$ it is completely normal; between these two regions is a region in which the structure undergoes a transition between these two types. The results of this investigation support this interpretation. In the region from $x=1.28$ to $x=2.0$ the oxygen parameter is essentially constant and in the region from $x=0.3$ to $x=1.38$ it increases in an approximately linear manner. The accuracy of the results is not sufficient to indicate if the oxygen parameter is essentially constant in the region from $x=0$ to $x=0.3$.

* Supported, in part, by the Office of Naval Research.
[1] Yearian, Kortright, and Langenheim, J. Chem. Phys. **22**, 1196 (1954).

**GA4. Ionic Equilibrium in a Series of Magnesium-Manganese Ferrites.*** C. J. KRIESSMAN AND S. E. HARRISON, *Remington Rand Inc.*—Samples of $Mg_yMn_{1-y}Fe_2O_4$ with values of $y=0$, 0.10, 0.25, 0.50, 0.75, 0.90, 1.0 have been sintered at 1500, 1400, and 1300°C and quenched from various temperatures in both air and water. Saturation magnetization and x-ray measurements have been made to determine the fraction $x$ of $Mg^{++}$ ions on $A$ sites. For samples sintered at 1400°C the saturation magnetization, $\mu_s$, decreases from 5.0 to 2.6 Bohr magnetons as $y$ increases from 0 to 0.75; as $y$ increases to 1.0, $\mu_0$ increases to 3.2. $Mg_{0.9}Mn_{0.1}Fe_2O_4$ has been sintered at various high temperatures up to 1500°C and quenched from temperatures between 1500°C and 400°C; saturation magnetization values and the resulting ionic distributions have been determined. These data fit a Boltzmann type distribution in which the activation energy is dependent on $x$: $\theta=\theta_0-\theta_1 x$. This behavior is analogous to the previously reported data on $MgFe_2O_4$.[1] The effects of sintering temperature, rapidity of quench, and chemical decomposition on the magnetic moments of this system will be discussed.

* Supported in part by the Office of Naval Research.
[1] Kriessman, Harrison, and Callen, Bul. Am. Phys. Soc. **30**, No. 2, 39 (X4) (1955).

**GA5. Effect of Aluminum on the Saturation Magnetic Moments of Iron-Cobalt Alloys.** B. R. COLES* AND W. R. BITLER, *Carnegie Institute of Technology* (introduced by J. E. Goldman).—It is well known that the saturation moment of iron (expressed in Bohr magnetons per iron atom) is almost unchanged by the addition of small amounts of such elements as zinc, aluminum, and silicon. This behavior is in marked contrast to that of nickel and it has been suggested that 3*d*-band holes of both spin directions exist in pure iron. It has further been suggested[1] that such a picture of iron leads to a reasonable interpretation of the flat maximum in the saturation moment against composition curve for iron-cobalt alloys. The saturation moments of various iron-cobalt alloys with additions of 5 percent and 10 percent of aluminum have been measured, and the preliminary results seem to bear out the above suggestions. Small aluminum additions decrease markedly the saturation moments of alloys on the cobalt-rich side of the iron-cobalt saturation moment maximum, but the saturation moment per transition metal atom of the iron-rich alloys is little affected by initial aluminum additions.

* On leave of absence from Imperial College, London, England.
[1] B. R. Coles and W. Hume-Rothery, Advances in Phys. **3**, 149 (1954).

**GA6. Ferromagnetic Structure of Uranium Hydride.** M. K. WILKINSON, C. G. SHULL, AND R. E. RUNDLE,* *Oak Ridge National Laboratory*.—Neutron diffraction patterns have been obtained for polycrystalline samples of $UD_3$ and $UH_3$ at various temperatures from 20°K up to room temperature in an investigation of the ferromagnetic structure which develops below 175°K. Coherent ferromagnetic scattering is found in several reflections at low temperatures and these disappear at temperatures in the vicinity of the reported Curie temperature. From these ferromagnetic reflections it is established that the lattice ordering is of simple ferromagnetic type with all atomic moments possessing closely the same moment value and oriented in the same direction. Paramagnetic diffuse scattering is seen at the higher temperatures and this taken with the ferromagnetic scattering suggests a magnetic form factor for the uranium ion which has strong orbital moment characteristics. Comparisons will be drawn between the observed form factor and those calculated for various electronic configurations of the uranium ion.

* At Ames Laboratory, Iowa State College.

**GA7. Ferromagnetism of Iron.** JOSEPH CALLAWAY, *University of Miami*.—A previous calculation of energy bands in unmagnetized iron[1] has been extended by the inclusion of magnetic effects. The change in exchange energy when one 3*d* electron per atom reverses its spin has been calculated from the Hartree Fock equations using a 3*d* wave function calculated for one of the unmagnetized crystal states. This energy is between $-1.58$ and $-1.23$ ev. The 3*d*–4*s* exchange tends to magnetize the 4*s* electrons, and about 0.1 4*s* electron per atom will participate in the magnetization. The magnetization tends to split the *d* bands into halves occupied by the different spins; corresponding levels are split by between 2.5 and 3.2 ev. The magnetization of a few 4*s* electrons is important in computing the increase in kinetic energy which opposes magnetization; this increase is computed from the density of states curve to be about 1.13 ev. The residual ferromagnetic tendency at absolute zero is thus between 0.10 and 0.45 ev per atom. Correlation effects are estimated to be small.

[1] J. Callaway, Bull. Am. Phys. Soc. **30**, No. 1, C1 (1955).

**GA8. Calculation of the Discontinuity in the Specific Heat of Gadolinium.*** HARRY A. BROWN, *Oberlin College*.—Using the cluster approach of Bethe-Peierls-Weiss[1] and adding the approximation that the spins can be considered to be classical vectors (gadolinium has a spin of 7/2) it is possible to calculate the discontinuity which occurs in the specific heat curve as it passes through the Curie temperature. The value predicted is 5.5 cal/M. The measured value[2] is 7.0 cal/M which is satisfactory in view of the limitations of the cluster approach. The theory also predicts a $1/T^2$ decrease above the Curie temperature which is verified by the experimental data.

* This research has been assisted by the Wisconsin Alumni Research Foundation.
[1] P. R. Weiss, Phys. Rev. **74**, 1493 (1948).
[2] Griffel, Skochdopole, and Spedding, Phys. Rev. **93**, 657 (1954).

## *Invited Paper*

**GA9. Spin-Wave Resonance in Ferromagnetic Metals.** G. T. RADO, *U. S. Naval Research Laboratory*. (30 min.)

THURSDAY AFTERNOON AT 2:00

(S. DE BENEDETTI presiding)

Continental Room

### *Invited Papers*

**H1. Yields of Mesonic *K* and *L* Series X-Rays.** J. B. PLATT, *University of Rochester.* (30 min.)

**H2. Intensities and Energy Shifts of Transitions in Pi-Mesonic Atoms.** M. B. STEARNS, *Carnegie Institute of Technology.* (30 min.)

**H3. Electric Quadrupole Transitions in Nuclei.** A. W. SUNYAR, *Brookhaven National Laboratory.* (30 min.)

**H4. Low-Energy Physics from a High-Energy Standpoint.** L. I. SCHIFF, *Stanford University.* (30 min.)

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THURSDAY AFTERNOON AT 2:00

Caribar Room

(E. P. WIGNER presiding)

### *Theoretical Physics II, Mainly Scattering Theory*

**HA1.** (Abstract withdrawn.)

**HA2. Variational Treatment of Elastic Scattering of Electrons from Hydrogen.*** M. C. NEWSTEIN,† *M.I.T.* (introduced by P. M. Morse).—Stationary expressions are derived for the direct and exchange scattering amplitudes.[1] Calculations are made of the direct amplitudes corresponding to scattering from a static, as well as from the actual, potential. Comparison of these two results shows that for 1.2 volts the major effect of polarization is to greatly decrease the direct cross section, while for 3.4 and 9.5 volts the major effect is a reduction in the forward and backward values of the direct amplitude. Calculations made of the complete cross sections including exchange give results in good agreement with those of Morse and Allis[2] for 3.4 and 9.5 volts. A cross-section theorem used by Boyet and Borowitz[3] is found to be not applicable to the determination of total cross sections when Born fields are used with the stationary expressions.

* Supported by the Office of Naval Research.

† Now at the Harvard College Observatory.

[1] The expression for direct scattering is the same as the one given by Borowitz and Friedman, Phys. Rev. **89**, 441 (1953).

[2] Allis and Morse, Phys. Rev. **44**, 269 (1933).

[3] Boyet and Borowitz, Phys. Rev. **93**, 1225 (1954).

**HA3. Many Body Effects in Nuclear Scattering of Electrons.** R. R. LEWIS, JR.,* *University of Michigan.*—Most present calculations of the nuclear scattering of electrons neglect transitions out of the ground state, in which case the scattering depends only on the ground-state charge distribution. In principle the scattering will actually depend as well on the pair distribution function, etc. The existence of these terms in second-order perturbation theory has been investigated,[1] and calculations have been made for light nuclei. The calculation involves a twofold assumption: that only plural scattering is important, and that the proton velocities are small compared to the electron velocity. These assumptions pertain to light nuclei, at not too high electron energies ($<300$ Mev). In the calculations a phenomenological pair distribution function is assumed for simplicity. Correction terms depending on the proton velocity are estimated as well. The dependence on the pair distribution function in the model independent region will also be discussed.

* Now at University of Notre Dame.

[1] Similar calculations have been discussed by L. I. Schiff, Bull. Am. Phys. Soc. **29**, No. 8, Q8 (1954).

**HA4. Proton Bremsstrahlung.** KERSON HUANG AND S. D. DRELL, *M.I.T.*—The differential cross section for proton bremsstrahlung is calculated for low-energy x-rays emitted by $E=2$ Mev protons which scatter in the field of tin nuclei ($Z=50$). This is essentially a classical problem of the dipole radiation from a proton moving in a Coulomb field since the proton's deBroglie wavelength is much shorter than the distance of closest approach to the nucleus. However, the classical orbit calculation for x-rays emitted at 90° to the proton beam in a 3 kev energy interval about $\hbar\omega=150$ kev predicts a differential cross section, $\sigma_c(90°)=2.1\times10^{-31}$ cm², in disagreement with the experimental result of H. Mark,[1] $\sigma_{exp}(90°)=1.3\pm0.5\times10^{-31}$ cm². Since corrections due to shielding by the orbital electrons and due to higher multipoles are negligible, this discrepancy must be due to quantum corrections resulting from the energy loss to radiation. We have expanded the exact quantum-mechanical matrix element for dipole bremsstrahlung, as derived by Sommerfeld, in a power series in $\hbar\omega/E$. Keeping the zero- and first-order terms, we have carried out the necessary integrations and have obtained a correction which lowers the calculated cross section by 25 percent in agreement with experiment.

[1] H. Mark, Bull. Am. Phys. Soc. **29**, No. 8, Berkeley Meeting, 1954.

**HA5. Quantum Calculation of Coulomb Excitation.** L. C. BIEDENHARN, *The Rice Institute.*—The usual treatment of Coulomb excitation employs a semiclassical approximation, and the validity of this approach has been the subject of recent investigations.[1] The quantum treatment[2] of the excitation, and the directional correlation parameters, reduces ultimately to consideration of radial Coulomb matrix elements for arbitrary angular momenta. These integrals define in general functions of the Appell type. (The electric dipole radial matrix elements are found to be the exception.) The relevant properties of these matrix elements, recursion formulas, series, and asymptotic expansions will be given; comparison will be made to approximate evaluations. The more amenable special cases of *1.* no energy loss, and *2.* the approach to the classical limit will be discussed in detail.

[1] G. Breit and P. B. Daitch, Phys. Rev. **96**, 1447 (1954); P. B. Daitch *et al.*, Phys. Rev. **96**, 1449 (1954); L. C. Biedenharn and C. M. Class, submitted to Phys. Rev.
[2] L. C. Biedenharn and M. E. Rose, Oak Ridge Natl. Lab. 1789, Sept. 1954.

**HA6. Multiple Coulomb Scattering Including Nuclear Size Effects.*** WILLIAM T. SCOTT, *Smith College.*—An alternative method to that of Cooper and Rainwater[1] has been developed for calculating the multiple Coulomb scattering in thick layers of fast-charged particles sufficiently energetic to show a noticeable influence of the finite size of nuclei. The usual Molière theory is modified by the inclusion of a suitable nuclear form factor, expressed as a single or double Fourier transform integral. The correction term to the Molière exponent can be written as the form factor integral with the Fourier kernel replaced by a modified expression involving only elementary functions, thus readily allowing the inclusion of various form factors. For the Born approximation, the integral on evaluation reduces to terms of Molière type plus terms whose exponentials can be fitted to within 1 percent by a sum of Gaussians. The final calculation amounts to a re-use of Molière's tables with different coefficients and normalizations. These results, and calculations with Cooper and Rainwater's form factor, will be presented and compared with other calculations and available experimental results on $\mu$-meson scattering.

* Work performed while the author was a visitor at Brookhaven National Lab. and at the Nat. Bur. Standards. Research being continued under a grant from the Nat. Sci. Foundation.
[1] L. N. Cooper and J. Rainwater, Phys. Rev. **97**, 492 (1955).

**HA7. Proton-Proton Scattering at High Energies.** ROBERT SERBER, *Columbia University,* AND WILLIAM RARITA, *Brooklyn College.*—The elastic proton-proton scattering distribution at 1 Bev as measured at the Brookhaven Cosmotron by Smith, McReynolds, and Snow agrees remarkably well within experimental error with a simple model. We assume that each proton acts as a classical black sphere of radius $R$ for the wave of the other. Thus the total cross section is $2\pi R^2$, and the angular distribution is proportional to $J_1^2(kR\sin\theta)/\sin^2\theta$. Using the total cross section measured by Chen, Leavitt, and Shapiro, we determine $R$. As $k$ is known from the energy, the shape of the distribution is now uniquely established. A by-product of the calculation is the total elastic cross section which is estimated to be 20.7 mb.

**HA8. Elastic Scattering of 17 Mev Protons by Nuclei.*** W. ARON, J. S. MCINTOSH, AND G. SCHRANK, *Princeton University,* AND J. H. BIGELOW, *Institute for Advanced Study.*—A five-parameter optical model based upon a complex well with a phenomenological spin-orbit term is employed to analyze the elastic scattering data for 17 Mev protons on various nuclei obtained by Schrank[1,2] and Dayton.[1,3] The nuclear potential chosen consists of a complex square well with its edge adjusted to join smoothly at bottom and zero by a third degree polynomial. The nuclear spin-orbit term is of the Thomas type, with adjustable real magnitude. The charge density is taken to be proportional to the well depth, and the corresponding Coulomb potential calculated. From this potential, wave functions are calculated, phase shifts determined, and cross sections obtained. These calculations are performed on the electronic computer at the Institute for Advanced Study.

* Work supported by the Atomic Energy Commission and the Higgins Fund.
[1] I. Dayton and G. Schrank, Phys. Rev. (to be published).
[2] G. Schrank, Bull. Am. Phys. Soc. (this issue).
[3] I. Dayton, Phys. Rev. **95**, 754 (1954).

**HA9. Nucleon Scattering by Nuclei at High Energies.** I. I. SHAPIRO, *Lincoln Laboratory,* AND R. J. GLAUBER, *Harvard University.*—The accuracy of the optical approximation for both neutron and proton scattering has been tested by comparing with exact phase-shift calculations. The potential employed was a complex square well combined with the coulomb potential of a uniformly charged sphere. Parameters were chosen appropriate to carbon at 96 Mev. For proton scattering the results show excellent agreement. The Coulomb interference region is reproduced quite accurately, and the comparison extends satisfactorily to substantially larger angles. For neutrons better agreement is found than has been reported,[1] probably due to a different approximation in the correspondence of parameters. Comparison of the neutron and proton results shows considerable Coulomb interference for angles smaller than 20° and negligible effects beyond 25°. Calculations of Coulomb interference effects in the proton polarizations resulting from spin-orbit potentials will also be discussed.

[1] S. Pasternack and H. Snyder, Phys. Rev. **80**, 921 (1950).

**HA10. Theory of Nucleon Transfer.*** G. BREIT, *Yale University.*—In the calculation of nuclear cross sections, it is helpful to obtain the adiabatic approximation wave function for a particle which is shared by two nuclei. Applications of the Rayleigh-Schrödinger perturbation method can be awkward on account of the entrance of wave functions for the continuum which do not have the barrier penetration properties characteristic of the actual function. A method employing Green's function for the wave equation in the absence of localized nuclear potentials has been worked out leading to expansions free of the difficulty mentioned. The eigenvalue problem contains depths of localized potentials as parameters. There is a restriction in the method regarding absence of overlap of the potentials. A correction for the change in energy is included. The method is intended for cross-section calculation in heavy-particle bombardment reactions.

* Supported by the Office of Ordnance Research, U. S. Army.

**HA11. Inelastic Scattering of Nucleons by a Dynamic Nuclear Wall.** DAVID M. CHASE, *Los Alamos Scientific Laboratory.*—The coupling between collective- and individual-particle motions envisaged in the collective model provides in nuclear scattering a mechanism for energy exchange between incident nucleon and target nucleus. For target nuclei near closed shells this nucleon-nuclear wall interaction would excite principally the fairly pure vibrational levels expected for such nuclei; for target nuclei far from closed shells and strongly deformed, the interaction would excite principally rotational levels. A one-dimensional model has been used to study numerically the features of such interaction, estimate the magnitude of the resulting cross sections, and compare two different methods of calculation. One method is that formulated by Bohr and Mottelson.[1] The other is based on the use of adiabatic nucleonic wave functions for the scattering process and seems especially appropriate when the coupling is strong and the collective levels of the target closely spaced. It is proposed subsequently to apply this method to the calculation of cross sections for rotational excitation. The results in one

dimension indicate average cross sections for neutrons of the order of several percent of geometric at moderate energies.

[1] A. Bohr and B. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 27, No. 16 (1953).

**HA12. Deuteron Cross Sections at High Energies.** R. J. GLAUBER, *Harvard University.*—Recent experiments indicate lack of additivity of the neutron and proton cross sections in deuterium at energies as high as 1.4 Bev. For example, direct measurement of the $n$–$p$ total cross section there gives[1] $\sigma(n,p)$ = 43 mb, while, with incident protons, deuterium-hydrogen subtraction yields[2] $\sigma(p,d-p)=33$ mb. To consider these effects, a generalization of the optical model has been constructed for the treatment of collisions with two-body systems in the high-energy limit. We assume that the incident particle wavelength is smaller than the ranges of interaction, and that the ranges at these energies are smaller than the deuteron. It may then be shown generally that the deuteron total cross section is $\sigma_d=\sigma_n+\sigma_p+4\pi\lambda^2\,\mathrm{Re}[f_n(0)f_p(0)](r^{-2})_D$ where $\sigma_n$ and $\sigma_p$ are the free neutron and proton cross sections, $f_n(0)$ and $f_p(0)$ are the elastic forward scattering amplitudes, and $r$ is the neutron-proton separation, whose inverse square is averaged in the deuteron. In particular, for purely absorptive interactions the forward amplitudes are imaginary and $\sigma_d=\sigma_n+\sigma_p-(4\pi)^{-1}\sigma_n\sigma_p(r^{-2})_D$, a result easily interpreted in terms of an eclipsing effect. Estimates of the interference term for incident protons are 9 and 17 mb. for deuterons with square-well and Hulthén potentials, respectively.

[1] Coor, Hill, Hornyak, Smith, and Snow. Phys. Rev. (to be published).
[2] Chen, Leavitt, and Shapiro (private communication). See also Phys. Rev. 95, 663 (1954).

**HA13. Scattering and Potential.** JOHN A. WHEELER, *Princeton University.*—For spherically symmetrical potentials satisfying a certain boundedness condition, it is known that the potential is uniquely determined by the phase shifts (1) for all $l$'s and all energies, provided the data are mutually consistent; or (2) for one $l$ and all energies, provided that for this $l$ value either (a) there exist no bound states or (b) one knows for each bound state its energy and a certain number defined by Jost and Kohn characteristic of that state. It is shown that these quantum results and the characteristic numbers of Jost and Kohn possess a simple interpretation in the JWKB semi-classical analysis of the connection between phase shift and potential. This same analysis leads to a third conclusion, that the potential is uniquely determined by the phase shifts for a single energy and all $l$.

**HA14. Scattering Approximations Using Plane Wave Trial Functions.** J. MAYO GREENBERG, *Rensselaer Polytechnic Institute.*—Several approximations to the total amplitude of scattering by a potential involve integrations similar to those required for evaluating the second Born approximation. This is certainly obvious in the Schwinger variational principle. It is also true for another variational principle[1] in case the trial functions are restricted to those of the plane-wave type. It can then be shown that the imaginary part of the scattering amplitude, which is an integral of a product of scattering amplitudes, can be put in a form which is the imaginary part of the second Born approximation. The required integration is apparently only possible with plane wave trial functions and has already been performed independently by numerous authors for the Yukawa potential (or for linear combinations thereof). It can also be done approximately, under suitable conditions, for the square well and, in fact, exactly for zero-angle scattering. Calculations are now in progress which will aid in the choice of the most successful approximation which for analytical simplicity requires plane-wave trial functions.

[1] J. M. Greenberg, Bull. Am. Phys. Soc. 30, No. 1, 50 (TA1).

**HA15. Scattering Analysis.** WILLIAM RARITA, *Brooklyn College and Case Institute of Technology.*—The elastic-scattering cross section usually expressed in terms of the phase shifts $\delta_l$ becomes complicated when there is interference among the phases. However, if the real parts of the phase amplitudes i.e. of the $1-\exp 2i\delta_l$ are employed as variables the scattering distribution is then simple and, in fact, merely algebraic in nature. The great advantage of such a representation is in the ease of following the analytic behavior of the solutions, say, as a function of the energy. In the case of $\pi^+-P$ at low energies we can solve for each $\cos 2\delta_l$ in terms of measurable quantities. If there is absorption we have to introduce the imaginary parts of the phase amplitudes as extra variables. Results for the $\pi^+-P$ and $P-P$ scattering will be discussed.

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## FRIDAY MORNING AT 9:30

Lisner Auditorium

(H. A. BETHE presiding)

### *Symposium in Memory of Enrico Fermi*

**J1. The Fermi Statistics and Its Applications.** F. SEITZ, *University of Illinois.* (25 min.)
**J2. Beta Decay.** E. KONOPINSKI, *University of Indiana.* (25 min.)
**J3. Neutron Physics.** EMILIO SEGRÈ, *University of California, Berkeley.* (30 min.)
**J4. Atomic Energy.** W. H. ZINN, *Argonne National Laboratory.* (30 min.)
**J5. Mesons.** H. L. ANDERSON, *University of Chicago.* (30 min.)

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## FRIDAY MORNING AT 9:30

Bergundy Room

(E. L. HUDSPETH presiding)

### *Transmutation and Nuclear Energy Levels, I*

**K1. A Study of the Reactions $H^3(d,n)\alpha$ and $He^3(d,p)\alpha$.*** JOHN L. JOHNSON AND WILLIAM S. PORTER, *Yale University.*—The total cross sections for the reactions $H^3(d,n)\alpha$ and $He^3(d,p)\alpha$ have been fitted with the Breit-Wigner one level formula using $S$-wave deuterons, assuming that only one total angular momentum state is effective. A fit to the differential

scattering cross section for deuterons on $He^3$ consistent with the reaction fits has been obtained using a one-body model with the Coulomb field cut off by a square nuclear well. Satisfactory fits to the reaction data were found using several types of energy dependence[1] of the $\Gamma$ suggested by different models of the resonance. The effect of varying the nuclear radius has been investigated. Comparison of widths reduced in the above manner is consistent with charge symmetry of the nuclear forces within the accuracy of the calculations.

* This research was supported by the Office of Ordnance Research, U. S. Army.
[1] G. Breit, Phys. Rev. **58**, 506 (1940); **69**, 472 (1946), E. P. Wigner, Phys. Rev. **70**, 15 (1946); **70**, 606 (1946).

**K2. Energy Levels of the Isobars $Li^6$–$He^6$.** K. W. ALLEN, E. ALMQVIST,* AND C. B. BIGHAM,* *University of Liverpool, England.*—The reactions $Li^7(He^3,\alpha)Li^6$ and $Li^7(t,\alpha)He^6$ have been studied. Excitation energies in Mev of the levels observed in $Li^6$ with their widths given in brackets are: 2.19 (<0.1), 3.56±0.06 (<0.1), 4.3±0.02 (?), 5.35±0.07 (<0.1), 6.63 ±0.08 (<0.2), and 7.40±0.10 (0.6). Less certainly identified are levels at 5.6±0.2 (2.0), 8.37±0.08 (<0.2), and 9.3±0.2 (0.6). Recoil $Li^6$ ions of energy corresponding to the 3.56 Mev level were observed, showing that it does not emit heavy particles and is the $\gamma$-emitting state identified by Day and Walker.[1] The levels at 2.19 and 4.3 Mev are also observed in the scattering of deuterons by helium[2] and hence have isotopic spin T=0. In $He^6$, levels at 1.71 (<0.1) and possibly 3.4 (<0.3) were observed. These appear to be analogs of the levels in $Li^6$ at 5.35 and 6.63 Mev. The sharp 5.35 level in $Li^6$, therefore, probably has T=1 and properties $2^+$, and is not the $1^+$ state required near this energy by the $(d,\alpha)$ scattering analysis. However, the reaction data are consistent with a broad $1^+$ level at 5.6 Mev.

* Present address Chalk River Laboratory.
[1] Day and Walker, Phys. Rev. **85**, 582 (1952).
[2] Galonsky and McEllistrem, Phys. Rev. **96**, 826A (1954).

**K3. $He^3$ and T Reactions in Some Light Elements.** E. ALMQVIST,* K. W. ALLEN, AND C. B. BIGHAM,* *University of Liverpool, England.*—By equipping the Liverpool 1-Mev accelerator with a gas recovery system it was possible to make a systematic study of $He^3$ and triton reactions. Ten ml of $He^3$ and 10 ml of hydrogen containing a few percent tritium were available. A proportional counter, a magnetic analyzer, a NaI crystal spectrometer, and photographic emulsions were used to study the charged reaction products. Targets of $Li^6$, $Li^7$, $Be^9$, $B^{10}$, $B^{11}$, $C^{12}$, $C^{13}$, $N^{14}$, $O^{16}$, and $F^{19}$ were bombarded. Energy distributions of the reaction products of (1) $Li^6(He^3,\alpha)Li^5$, (2) $Li^6(He^3,p)Be^8$, (3) $Li^7(He^3,p)Be^9$, (4) $B^{10}(t,\alpha)Be^9$, and (5) $B^{10}(He^3,\alpha)B^9$ will be reported. The proton distributions from $Li^6$ and $Li^7$ agree with those of the Oak Ridge group.[1] In reaction (3) were observed the following levels in $Be^9$, with widths shown in brackets: 1.80±0.1 (<0.4), 2.39±0.08 (<0.2), 3.06±0.08 (<0.3), 4.74±0.08 (1.2) Mev, and possibly one at 9.1±0.2 (1.2) Mev. Also deuterons from the reaction $Li^7(He^3,d)Be^8$ were observed. Reaction (4) shows levels at 2.39 and 3.06 in $Be^9$. Reaction (5) shows only one excited state of $B^9$ at 2.58±0.13 Mev. Reaction (1) shows $\alpha$ peaks of 8.3 and 7.5 Mev energy.

* Present address Chalk River Laboratory.
[1] Moak, Good, and Kunz, Phys. Rev. **96**, 1363 (1954).

**K4. Angular Distributions and Angular Correlations in $Be^9(d,p)Be^{10}$, and $B^{10}(d,p)B^{11}$.*** S. A. COX AND R. M. WILLIAMSON, *Duke University.*—Angular correlation measurements have been made in the reactions $Be^9(d,p)Be^{10}$ and $B^{10}(d,p)B^{11}$ for the purpose of investigating the validity of the angular correlation theory[1] in stripping reactions. The angular distribution of group $P_1$ in $Be^9(d,p)Be^{10}$ has been measured previously[2] and is characteristic of $L_{neutron}=1$. Using the known ground state spins of $Be^9$ and $Be^{10}$ and assuming $J=2$ for the 3.37 Mev state in $Be^{10}$, the correlation functions corresponding to the two possible channel spins have been calculated. The measured correlation agrees well with the function for which the channel spin =1. The angular distributions of the five longest range proton groups in $B^{10}(d,p)B^{11}$ have been measured from $\theta_p=15°$ to 130°. At $E_d=3.90$ Mev groups $P_0$, $P_2$, and $P_4$ have strong stripping peaks between 25 and 30 degrees corresponding to $L_{neutron}=1$ in agreement with previous data at $E_d=7.7$ Mev.[3] Angular correlation measurements were made on groups $P_2$ and $P_4$. The measured correlations will be compared with the possible theoretical correlation functions.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] Biedenharn, Boyer, and Charpie, Phys. Rev. **88**, 517 (1952).
[2] Fulbright, Bruner, Bromley, and Goldman, Phys. Rev. **88**, 700 (1952).
[3] N. T. S. Evans and W. C. Parkinson, Proc. Phys. Soc. (London) **A67**, 684 (1954).

**K5. Energy Levels of $B^{13}$, $C^{13}$, $C^{13}$, and $F^{21}$.** C. B. BIGHAM,* K. W. ALLEN, AND E. ALMQVIST,* *University of Liverpool, England.*—The long range particles emitted from targets of $B^{10}$, $B^{11}$, $C^{13}$, $C^{13}$, $N^{14}$, $O^{16}$, and $F^{19}$ bombarded by 900 kev $He^3$ and T ions have been studied using photographic emulsion and NaI crystal techniques. In each case the observed proton groups yield information about the level structure of the residual nucleus with an estimated error in energy of less than ±0.1 Mev. In $B^{13}$, levels were observed at excitations of 0.94, 1.65, 2.61, 3.37, 3.75, and 4.46 Mev; in $C^{13}$ at 4.43, 7.77, 9.61, 10.75, 11.83, 12.76, 13.31, 13.97, 15.10, 16.04, and 16.57 Mev; in $C^{13}$ at 3.08, 3.77, 6.89, 7.63, 8.96, 10.00, 10.99, and 11.67 Mev. The reaction $F^{19}(t,p)F^{21}$ was observed. The data yield a mass defect for $F^{21}$ of 6.37±0.1 Mev, and it is stable against heavy-particle breakup. Excited states of $F^{21}$ at 0.89 Mev and possibly 3.34 and 4.01 Mev were observed.

* Present address Chalk River Laboratory.

**K6. $C^{12}(p,pn)C^{11}$ Cross Section for 340 Mev Protons.*** W. E. CRANDALL, W. BIRNBAUM, G. P. MILLBURN, AND R. V. PYLE, *University of California, Berkeley.*—The cross section for the $C^{12}(p,pn)C^{11}$ reaction was measured by monitoring the proton beam with a Faraday cup and the $C^{11}$ decay with a $4\pi$ gas counter. The self-absorption of the thin polystyrene foils was measured by uniformly activating thin foils and counting these foils singly and in combinations to eliminate the foil weight from the determination. Also simultaneous activation of plastic scintillators determined a zero foil thickness point by $\beta$–$\gamma$ coincidence technique. The effects of the self-absorption curve on the cross section previously determined with thin polystyrene foils will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**K7. Protons from the Deuteron Bombardment of $C^{13}$.†** T. W. BONNER, ALFRED A. KRAUS, JR., J. T. EISINGER,* AND J. B. MARION, *The Rice Institute.*—Excitation functions and angular distributions of the reaction $C^{13}(d,p)C^{13}$ have been measured from $E_d=2.0$ Mev to $E_d=5.0$ Mev, where $E_d$ is the deuteron energy. Excitation functions were taken at angles of observation of 30°, 90°, and 150°. Resonances were found at $E_d=2.53$, 2.73, 3.02, 3.34, 3.93, and 4.76 Mev. These resonances show interference effects. Excitation functions were measured at 10°, 50°, 60°, 70°, 80°, 90°, 100°, 110°, 120°, and 130° for $E_d=3.2$ Mev to $E_d=4.2$ Mev. The analyses of these data will be discussed in terms of Butler stripping and resonant compound nucleus formation. The angular distribution at 3.29 Mev is in agreement with that of Holmgren *et al.*[1]

† Supported by the U. S. Atomic Energy Commission.
* Now at Bell Laboratories, Murray Hill, New Jersey.
[1] Holmgren, Blair, Simmons, Stratton, and Stuart, Phys. Rev. **95**, 1544 (1954).

**K8, $(d,p)$ Reactions from $C^{13}$ and $C^{14}$.*** J. N. McGruer, E. K. Warburton, and R. S. Bender, *University of Pittsburgh.*—Observations have been made of the proton groups resulting from the deuteron bombardment of a thin carbon target. 14.5 Mev deuterons were incident upon a target of elemental carbon[1] (enriched to 60 percent $C^{13}$) and outgoing protons were analyzed with a magnetic spectrometer. Seven previously reported levels were observed in $C^{13}$ and four in $C^{14}$. In addition twelve new levels were observed, three in $C^{13}$ at 7.47, 9.50 and 9.90 Mev, and nine in $C^{14}$ at 6.59, 7.35, 8.32, 9.80, 10.43, 10.50, 12.60, 12.85, and 12.96 Mev.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] We are indebted to T. Lauritsen for furnishing the target.

**K9. Differential Cross Sections for $C^{13}+d$ Reactions.*** M. T. McEllistrem, Ren Chiba, R. A. Douglas, D. F. Herring, and E. A. Silverstein, *University of Wisconsin.*—Differential cross sections for laboratory angles between 24 degrees and 167 degrees have been measured in a differentially pumped gas scattering chamber as a function of deuteron energy (2.5–3.4 Mev) for elastic scattering, and for the $(d,p)$ reactions to the ground and 3.08-Mev level of $C^{13}$. Absence of systematic errors was indicated by also measuring the $p$–$p$ cross sections. The ground state data confirm and extend our earlier measurements. Resonances in the elastic scattering were observed at 2.51, 2.74, 2.96, 2.99, 3.12, and 3.39 Mev. The resonances at 2.51 and 2.74 Mev were also observed in the $(d,p)$ reactions. The combined effect of some or all of the resonances at 2.96, 2.99, and 3.12 Mev was also observed in the $(d,p)$ data. An angular distribution for the $(d,p)$ reaction to the first excited state on the 2.74-Mev resonance showed a large cross section for angles near 180 degrees. Above the resonance, the forward stripping peak (corresponding to $l_n=0$) increased markedly, whereas the large angle cross sections were greatly diminished. Interference between stripping and compound nuclear contributions to the $(d,p)$ reactions is clearly indicated. Some success has been attained in attempts to analyze the data into compound nuclear and stripping contributions.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

**K10. Energy Dependence of the Cross Sections for the Reactions $C^{13}(d,n)N^{14}$ and $C^{13}(d,t)C^{11}$ up to $E_D=20$ Mev.*** D. H. Wilkinson,† *Brookhaven National Laboratory.*—The energy dependence of the integrated cross section for the reaction $C^{13}(d,n)N^{14}$ leading to the *ground state of $N^{14}$ only* has been measured as a function of deuteron energy up to $E_D=20$ Mev. The cross section falls rather smoothly above $E_D=6$ Mev, rather more slowly than is suggested by the simple Born approximation stripping theory, and substantially more slowly than would be expected on the basis of compound nucleus formation. The cross section at $E_D=8$ Mev is 100 mb. The cross section for the reaction $C^{13}(d,t)C^{11}$ rises rapidly from threshold ($E_D=14.5$ Mev) to $E_D=20$ Mev where the cross section (to all available states of $C^{11}$) is 10 mb. This cross section may not be explained on the basis of the compound nucleus model even under the rather unlikely assumption of a triton reduced width as great as that for a neutron, and it seems most likely that pickup is involved.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† On leave from Cavendish Laboratory, Cambridge, England.

**K11. Angular Distribution of Proton Groups from the $N^{14}(d,p)N^{15}$ Reaction.*** R. D. Sharp, A. Sperduto, and W. W. Buechner, *M.I.T.*—A study of the angular distribution of the proton groups for the $N^{14}(d,p)N^{15}$ reaction has been undertaken with the ONR–MIT electrostatic generator in conjunction with the new broad-range spectrograph. A series of exposures have been made at a deuteron bombarding energy of 7 Mev and at angles between 5 and 55 degrees in 5-degree steps, and between 60 and 110 degrees in 10-degree steps. The target consisted of a thin nylon film supported by an evaporated layer of gold. The energy spectrum observed over the 30-inch length of nuclear track plates was such that sixteen proton groups[1] from the $N^{14}(d,p)N^{15}$ reaction were recorded simultaneously at each angle. These groups covered the region of excitation in $N^{15}$ from the pair of levels at 5.3 Mev to about 11 Mev. Angular-distribution curves for a number of these groups have thus far been obtained. Spin and parity assignment for the various levels are being made on the basis of a Butler-type stripping analysis.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Sperduto, Buechner, Bockelman, and Browne, Phys. Rev. 96, 1316 (1954).

**K12. A 2-State at 8.85 Mev in $O^{16}$.*** B. J. Toppel, D. H. Wilkinson,† and D. E. Alburger, *Brookhaven National Laboratory.*—The bombardment of $F^{19}$ by 3.1- to 4.1-Mev protons from the Brookhaven National Laboratory research Van de Graaff gives rise to a gamma ray of energy $2.73\pm0.02$ Mev as determined by single crystal NaI(Tl), and by three crystal pair spectrometer measurements. This gamma ray is shown to be in coincidence with the 6.14-Mev gamma ray from the 3-state of $O^{16}$ and therefore comes from a state in $O^{16}$ formed in the reaction $F^{19}(p,\alpha)O^{16}$ which is stable against alpha-particle emission although such emission is energetically possible. A weak gamma ray of $1.71\pm0.02$ Mev is found to be in coincidence with gamma radiation between 6.3 and 8 Mev, as is a yet weaker line of $1.92\pm0.02$ Mev. These latter transitions are to the $1-$ and $2+$ states at 7.12 and 6.91 Mev, respectively. These observations fix the new state in $O^{16}$ at $8.85\pm0.02$ Mev and, together with the observation that the ground state transition is not seen, imply its characteristics as $2-$. The implications of this result for the alpha-particle model of $O^{16}$ will be discussed. The occurrence of the 1.92 Mev line is in violation of the isotopic spin selection rule on $E1$ radiations in self-conjugate nuclei.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† On leave from Cavendish Laboratory, Cambridge, England.

**K13. Inelastic Scattering at 19 Mev Protons by $O^{16}$: (A) Proton Groups.*** R. Sherr and W. F. Hornyak,† *Princeton University.*—The $\alpha$-particle model of $O^{16}$ predicts the existence of $2\pm$ doublets which have been unsuccessfully looked for in the past. To investigate this problem, 19.0-Mev protons were used to excite $O^{16}$ by inelastic scattering. The external beam of the Princeton cyclotron was automatically controlled to $\pm10$ kev in mean energy. Scattered protons were detected with a NaI(Tl) crystal whose energy response was calibrated by $p$-$p$ scattering. Observations on $O^{16}$ were made at 10 angles between 40° and 165° using targets of cellulose acetate, $PbO_2$, and $U_3O_8$. In addition to the doublets at 6.1 and 7.0 Mev (unresolved in this experiment) seven states were found: 8.85, 9.84, 10.34, 11.08, 11.51, 12.03, and 12.52 Mev; the average energy deviation in the various determinations for each level was approximately 30 kev. The 11.08 and 12.03 levels are new; the others agree within 20 kev with previously published values, except for the 8.85 Mev level previously reported as $8.6\pm4$ Mev. The integrated cross sections in millibarns are roughly 58 and 34 for the 6- and 7-Mev doublets and 28, 8, 8, 20, 11, 6, and 11, respectively, for the higher levels.

* Work supported by the U. S. Atomic Energy Commission and The Higgins Fund.
† On leave from Brookhaven National Laboratory.

**K14. Inelastic Scattering of 19 Mev Protons by $O^{16}$: (B) Gamma Radiation.*** W. F. Hornyak† and R. Sherr, *Princeton University.*—The spin and parities of the levels of

$O^{16}$ listed in the preceding abstract are known from $C^{13}$ $(\alpha,\alpha)$ and $N^{15}$ $(p,\alpha)$ work, except for the levels at 8.85, 11.08, and 12.03 Mev. If any of the latter states are $2^-$ they could not decay by $\alpha$-particle emission and would decay by $\gamma$-ray emission. With a 30 mμsec NaI(Tl) coincidence apparatus, coincidence spectra for both protons at 150° and $\gamma$ rays at 90° were observed. In addition to $p$-$\gamma$ coincidences for the protons leading to the 6- and 7-Mev states, conspicuous $p$-$\gamma$ coincidences were observed only for the groups to the 8.85, 11.08, and 12.52-Mev levels. The 12.52-Mev level showed a ~4-Mev coincidence $\gamma$ ray consistent with decay by $\alpha$-particle emission to the first excited state in $C^{13}$. Only cascade $\gamma$ transitions through the states at 6- and 7-Mev were observed for both the 8.85 and 11.08 states. A reasonable interpretation assigns a spin and parity of $2^-$ to the latter levels, and assumes cascading through the $3^-$ level at 6.13 Mev and the $1^-$ level at 6.9 Mev. The weak proton group leading to the 12.03-Mev state also showed probable $p$-$\gamma$ coincidences.

* Work supported by the U. S. Atomic Energy Commission and The Higgins Fund.
† On leave from Brookhaven National Laboratory.

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## FRIDAY MORNING AT 9:30

Caribar Room

(H. L. DRYDEN presiding)

### *Fluid Dynamics; General Physics*

**KA1. Radiation from a Strong Shock Front in Krypton.*** E. B. TURNER, *University of Michigan.*—Petschek[1] observed that a very strong shock front in argon is usually seen as a bright luminous line. We have shown from wave-speed photographs in krypton with a revolving drum camera at an angle to the shock tube, that the luminosity is homogeneous across the front and not a wall effect. Another series of wave-speed photographs were made with a wedge interference filter placed in front of a horizontal slit on the shock tube. These showed mainly line radiation, but the lines were not those of krypton. At the suggestion of C. W. Peters, a spectrum was obtained by rotating the film drum at such a speed that the image of the shock front was stationary on the film. The Swan bands of carbon, which arise from organic vapors, as well as the lines of Ca and Na were observed. The sharp luminous front is apparently due to inelastic collisions between these vapors and krypton atoms in the zone where translational equilibrium is not yet established.

* Supported by the Air Research and Development Command.
[1] H. E. Petschek, Phys. Rev. **84**, 614(A) (1951).

**KA2. Reflection of a Compression Wave from a Symmetrical Wedge.** R. W. SKULSKI* AND D. WEIMER,† *Armour Research Foundation.*—Compression waves generated by paper pistons accelerated by shock waves in a shock tube have been reflected from symmetrical wedges. Studies of the density fields in the interaction region have been made with an interferometer and the parameters, "wave age," distance up the wedge, and angle of incidence have been investigated over a range of incidence angles from 25° to 80° and "effective shock strengths" from $\xi=0.5$ to $\xi=0.9$. The limit of regular reflection for this type of wave is shown to exist theoretically and this limit has been verified experimentally. Beyond this limit a type of Mach reflection occurs.

* Askania Regulator, Chicago.
† Mechanics Research Department, American Machine and Foundry Co., Chicago.

**KA3. Shock Wave Spectroscopy.** RICHARD J. ROSA, *Cornell University.**—A moving film technique has been developed for photographing strong shock spectra. If the film is made to move at a velocity within 5 percent of that of the shock wave image, the exposure time is increased by twenty and the light from different regions of the shock is separated on the film. Space resolved spectra of Mach No. 10 shocks in argon were obtained. These indicate that the luminosity of the front[1] is due to impurities, specifically, carbon bearing compounds. It could be expected that the light emitted by minute traces of impurities would dominate the spectrum at the theoretical equilibrium temperatures at this Mach number. Experiments with a probe filled with liquid $N_2$ also indicate impurities are responsible. The spectra show the Swan bands of $C_2$ confined to a narrow region at the front, and the violet CN bands reaching a maximum intensity close to the front and tailing off behind. Lines due to metallic impurities such as Hg and Na are observed to start at or near the front and continue with constant intensity to the entropy line. Preliminary results of air spectra above $M=15$ will also be presented.

* This work was partially supported by the Office of Naval Research.
[1] H. E. Petschek, Phys. Rev. **84**, 614 (1951).

**KA4. Periodic Shock Production in Resonating Gas Columns.** GEORGE E. HUDSON AND ALFRED SAENGER, *New York University.*—Observations have been made of periodic shock waves produced in a tube closed at one end by a rigid wall and at the other by a piston vibrating in sinusoidal motion. Although the piston's amplitude is small, shocks are produced when the frequency is near the acoustic resonance frequency of the gas column. With a condenser pickup, pressure variations at several points at the tube wall have been measured as a function of frequency, as has the relative phase between the piston's motion and the peak pressure. A solution of the exact one-dimensional compressible flow equations subject to the first order (isentropic) shock boundary conditions—has been found for the comparable case of oscillating motion of a gas in a tube closed rigidly at both ends. The computed maximum gas displacement corresponding to our observed pressures indicates that the maximum gas displacement at the tube center is about the same as that computed from acoustic theory. Observations have also been made of two shocks colliding periodically at the tube center when the driving frequency is near that of the first acoustic harmonic.

**KA5. The Sonoluminescence of Water.*** D. SRINIVASAN AND L. V. HOLROYD, *University of Missouri.*—An effort has been made to establish the origin of the weak luminescence produced when water is irradiated by an intense ultrasonic beam. In order to promote cavitation it is necessary that the water be saturated with a gas. Water saturated with the following gases was studied separately using 800 kilocycle acoustic radiation: argon, oxygen, nitrogen, and helium. The intensity of luminescence increased with increasing solubility of the gas. The spectral distribution of this luminescence was determined with a photon counter in the interval from 2800 A

to 5500 A. The spectrum is continuous and corresponds to that of a blackbody at a temperature of the order of 10 000°K. An absorption spectrophotometer was used to determine the nature and quantity of any chemical products formed during the ultrasonic irradiation. Hydrogen peroxide was found in the case of oxygen saturated water but no chemical products were observed either in argon or helium solutions. Theoretical considerations of cavitation in Liquids by Noltingk and Neppiras[1] suggest the possibility of the production of high temperatures in the cavitation bubbles and our results seem to support this view.

* Supported in part by the National Science Foundation.
[1] B. E. Noltingk and E. A. Neppiras, Proc. Phys. Soc. (London) **B63**, 674 (1950).

**KA6. One-Dimensional Dispersion of Mass by Molecular and Turbulent Diffusion.*** B. A. FLEISHMAN, *Applied Physics Laboratory* (introduced by R. A. Alpher).—A given one-dimensional distribution of matter is dispersed under the combined action of molecular diffusion and turbulence. We derive here a formula for the mean concentration of dispersed matter, as a function of $x$ and $t$, in terms of the initial distribution, the coefficient of molecular diffusion, and the statistical properties of the turbulent velocity field. First the initial value problem for the diffusion-convection differential equation (for an arbitrary bounded convection field) is solved for the concentration $\sigma$ by perturbing with respect to the "magnitude" of the convection velocity. Then, assuming that we have a random convective velocity field (i.e., an ensemble of velocity fields) rather than one specific convection field, we take an ensemble average of the infinite series for $\sigma(x,t)$ obtained previously. In the resulting series for $\bar{\sigma}(x,t)$, the *mean* concentration, the zero-order term involves only the molecular diffusion coefficient and the initial distribution, while the $n$th-order term contains in addition the $n$th-order space-time correlation coefficient of the turbulent velocity field. The result is valid at small dispersion times or for small intensities of turbulence.

* This work was supported by the Bureau of Ordnance, U. S. Department of the Navy.

**KA7. Maximizing the Separation Factor of a Thermal Diffusion Column.*** J. W. CORBETT† AND W. W. WATSON, *Yale University*.—The separation factor, $q$, of a hot-wire thermal diffusion column for gaseous operation is a function of the radius, $r$, pressure, $p$, and temperature differential in the column. The relation describing the maximized $q$ with respect to $r$ is $K_d=2K_c$,[1] with $K_c$ and $K_d$ the convection- and diffusion-remixing factors, respectively. The condition describing maximized $q$ with respect to $p$ is $K_d=K_c$. (For want of information on parameter dependence the parasitic remixing factor, $K_p$, has been omitted from consideration.) The magnitude of the maxima for both criteria goes as $1/r$ (or $p^1$), therefore the smallest radius constructionally feasible should be chosen. The ratio of $q$ for $K_d=K_c$ (designated $q_1$) to that $q$ for $K_d=2K_c$, evaluated at constant $r$, goes as $(q_1)^{0.33}$, hence for the desired case of large $q$, the advantage of operating at $K_d=K_c$ (i.e., a higher pressure) is not inconsequential. The relationship between $q$ and the temperature difference is not a simple function and no general conditions can be established. A maximum of $q$ with respect to temperature may, or may not, occur in the operating region, and each case must be investigated numerically.

* Supported in part by the U. S. Atomic Energy Commission.
† General Electric Coffin Fellow.
[1] Jones and Furry, Revs. Modern Phys. **18**, 151 (1946).

**KA8. A Determination of Current in Absolute Measure.** RAYMOND L. DRISCOLL, *National Bureau of Standards* (introduced by F. B. Silsbee).—A steady current was measured in an absolute sense using a Pellat type electrodynamometer; simultaneously the same current was passed through a resistance whose value was known in units maintained at this Bureau. The current was adjusted beforehand to make the potential difference across the resistance equal to the emf of a standard cell whose value was known in units of emf as currently maintained. The numerical value of a current in terms of standards of emf and resistance has been found to be larger than its numerical value obtained from absolute measurements by 19 parts per million. Known uncertainties in the absolute measurement are estimated to be 6 parts per million.

**KA9. Transient Response of Cavity Resonator.** C. W. HOOVER, JR., *Bell Telephone Laboratories*.—The general transient response of a cavity resonator to pulse-modulated radio frequency power input is obtained by solution of the differential equations representing the resonator and coupling loop. The solution obtained gives the normalized resonator response in the undercoupled, critically coupled, and overcoupled cases when the rf input is at or near the resonator center frequency. In the critical and overcoupled cases it is shown that the response is modified by a cosinusoidal modulation factor when the frequency of the source is different than the frequency of maximum response, or the frequency remaining constant when the coupling between source and resonator is changed. This modulation factor gives rise to large amplitude oscillations in the response. The solution obtained is of interest where close coupling is used between power source and resonator as in linear accelerators and klystrons. The solution is approximate but the maximum error in the amplitude of the normalized response is $1/2Q_0$. The observed response of a particular cavity resonator is given and is shown to agree with the predicted response.

**KA10. Counting Efficiency of Electromechanical Message Registers.** GREGORY THEOCLITUS, *Air Preheater Corporation*, AND HOMER C. WILKINS, *Alfred University*.—The effect of the dead-time of nonjamming message registers on recorded counting rates has been investigated. A nonjamming message register is one which, when fed pulses at an increasingly high rate, will record at a rate asymptotically approaching the reciprocal of the dead-time. Using the Poisson distribution law for random events, the expected observed counting rate has been computed for various true counting rates in applications in which such a message register is preceded by electronic scaler circuits of various scale factors. It has been found that the expected curve of observed counting rate *versus* true counting rate is linear up to counting rates about one-half the asymptotic value, and then has several points of inflection and minima before leveling off at the asymptotic value of observed counting rate. Experiments using Geiger counters as sources of random pulses give results in good agreement with the theory. A discussion of the derivation of the curves and also an explanation of the minima will be given.

**KA11. Automatic Pressure Control System.*** D. F. HERRING, *University of Wisconsin*.—A constant pressure control system for a differentially pumped gas scattering chamber has been developed. An octoil-*S* filled manometer monitored by two photocells is used as a pressure detector. The octoil in the manometer is used as a cylindrical lens which focuses the light beams on the photocells. The signals from the two photocells are balanced against each other, thus making the instrument a null detector. The resulting error signal is then amplified and made to control the current through a gas flow regulating device. This device consists of a glass capillary of 15 mils inside diameter, through which is passed a nichrome wire of 10 mils diameter. By heating this wire with the current, the viscosity of the gas is altered, thus controlling the rate of flow of gas through the capillary. The present system controls the pressure to $\pm 0.03$ mm of octoil. Details of construction and operation will be presented.

* This work is supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

**KA12. Ultra High Speed Cine-Microscopy and Time Resolved Spectroscopy.** GEORGE HAUVER AND LOUIS ZERNOW, *Ballistic Research Laboratories.*—The technique previously described[1] for combining an ultra high-speed framing camera (framing rates $>10^6$/second) with a microscope in order to obtain cine-microscopic sequences of physical phenomena has been extended to higher magnifications (>200×). Considerably greater magnifications are still possible. Limiting factors will be discussed. Studies of the explosion of thin conducting films by means of electrical discharges will be described. A simple method for using the ultra high-speed framing camera for time-resolved spectroscopy will also be described and illustrated with spectrograms of exploding wires.[2]

[1] L. Zernow and G. Hauver, Bull. Am. Phys. Soc. **30**, No. 2, 28 (1955), abstract Q11.
[2] J. A. Anderson and Sinclair Smith, Astrophys. J. **64**, 295 (1926).

**KA13. Steady-State Calibration of Vibration Transducers at Accelerations up to ±4000 g.** T. A. PERLS, C. W. KISSINGER, AND D. R. PAQUETTE, *National Bureau of Standards.*—Details are presented for a new steady-state method for calibrating small vibration pickups at peak accelerations up to ±4000 g. The method uses a commercial vibration generator and 70-watt power amplifier designed for a maximum of ±50 g, together with a selection of resonant beams made from a fatigue-resistant chrome-vanadium steel. The mechanical $Q$ of the resonant system, which includes the beam, a clamping device, and the shaker armature, is of the order of 100 to 200. Beams with shapes other than rectangular have been tried in an effort to distribute the stresses, and one of the tapered beams has resulted in the highest accelerations so far. Sharp discontinuities in the beams, in particular holes used for clamping purposes, have to be avoided since they result in stress concentrations and in the initiation of cracks. Sample linearity data of small $BaTiO_3$ accelerometers will be shown. The method may also have application to fatigue testing.

**KA14. Rotational Oscillations of Electrostatically Charged Conductors.** OLEG YADOFF AND SOPHIE YADOFF.—When two or more fine wires are charged electrostatically (+) and (−), they commence evenly to rotate, the amplitudes and frequencies of rotation being functions of the potential, their diameters, and their distances from one another. These rotations occur whether the wires be arranged parallelly, obliquely, or perpendicularly to one another. In darkness the rotations of (+)-charged wires cut whitish-violet loops, whereas the rotations of the (−)-charged wires describe distinct luminous circles. The phenomenon occurs in air and various gases. Generally, amplitudes and frequencies are greater with ( ) charges. Rotations persist if only one wire is charged and the other is grounded or left suspended in the air. Authors' mathematical analysis follows current methods.

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## FRIDAY MORNING AT 9:30

## NBS, East Building

## (W. H. BRATTAIN presiding)

### *Semiconductors, II*

**L1. Microwave Magnetoconductivity Bridge for Semiconductors.*** SIMON FONER, H. J. ZEIGER, R. L. POWELL, AND BENJAMIN LAX, *Lincoln Laboratory.*—A sensitive microwave bridge at 9200 Mcps has been constructed to measure the magnetoconductivity of semiconductors. The apparatus permits rotation of the magnetic field relative to crystal orientation. Such measurements should yield information on the shape of the energy surfaces associated with the carriers. Variation of the temperature should provide information on the average effective mass of carriers as well as the temperature dependence of the scattering.[1] The method allows investigation of semiconductors which can not at present be studied by cyclotron resonance because of sample impurity. Many of the difficulties inherent in dc measurements, particularly at low temperatures, are eliminated, i.e., contact problems, thermal effects, etc. Furthermore, theoretical analysis of the data is simplified because conductivity rather than resistivity is measured. Changes of 0.04 percent in conductivity can be observed at present. Preliminary investigations of a number of semiconductors will be discussed.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] J. M. Goldey and S. C. Brown, Bull. Am. Phys. Soc., **20**, No. 1, 53 (1955), abstract V3; T. S. Benedict and W. Shockley, Phys. Rev. **89**, 1152 (1953).

**L2. Microwave Magnetoconductivity Effects in InSb.*** R. N. DEXTER AND BENJAMIN LAX, *Lincoln Laboratory.*—Using cyclotron resonance techniques[1] we have observed the magnetoconductivity of electrons and holes in polycrystalline and single-crystal InSb. The observations thus far have shown the nonresonant microwave absorption characteristic of $\omega\tau<1$, where $\omega$ is the angular frequency and $\tau$ is the scattering time. Low values of $\tau$ result from impurities and imperfect stoichiometry of the compound. In the most nearly perfect (polycrystalline) samples it was possible by means of curve fitting to determine that $\tau=0.2\times10^{-11}$ second (i.e. $\omega\tau=0.3$ at 23 000 Mcps). The average effective masses of electrons and holes were found to be approximately 0.02 $m_0$ and 0.3 $m_0$ respectively where $m_0$ is the free-electron mass. These values are consistent with those obtained from optical measurements.[2] In $n$-type samples the electrons had not frozen into the traps at 1.2°K resulting in carrier densities of the order of $10^{13}-10^{14}$ per cc. Complicated absorption effects in samples of thickness of about 0.3 mm arose from variations of microwave skin depth relative to sample thickness as a function of magnetic field and possibly from depolarization and plasma effects.[3]

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] Dexter, Lax, Kip, and Dresselhaus, Phys. Rev. **96**, 222 (1954).
[2] E. Burstein, Phys. Rev. **93**, 632 (1954).
[3] C. Kittel, Physica (to be published).

**L3. Recombination Processes in Tellurium.*** DAVID REDFIELD,† *University of Pennsylvania.*—The statistical treatment of recombination processes in semiconductors developed by Shockley and Read[1] has been applied to tellurium using a proposal advanced by Rittner.[2] Data reported earlier on the photoconductivity of tellurium as a function of light intensity at 100°K showed a transition from linear to square root dependence that was suggestive of direct recombination.[3] However, Rittner's considerations indicated the possibility of explaining such a dependence by recombination through traps under certain conditions. This possibility has been analyzed

for $p$-type material, and the physical consequences of these conditions considered in the light of available information on tellurium. Without any assumptions regarding the magnitude of the recombination coefficients involved, it seems possible to distinguish between the different recombination mechanisms. On the basis of such analysis, direct recombination appears to be dominant in tellurium.

* This work supported in part by the Office of Naval Research and the U. S. Air Force.
† Socony-Vacuum Oil Company Fellow.
[1] W. Shockley and W. T. Read, Phys. Rev. **87**, 835 (1952).
[2] E. S. Rittner, *Photoconductivity* (to be published).
[3] D. Redfield, *Photoconductivity* (to be published).

**L4. Galvanomagnetic Effects in Single Crystals of Antimony.*** H. J. JURETSCHKE AND S. J. FREEDMAN, *Polytechnic Institute of Brooklyn*, AND S. EPSTEIN, *Signal Corps Engineering Laboratory*.—At room temperature the change of the resistivity tensor of antimony with magnetic field $H$ can be expressed as a rapidly converging power series in $H$. For $H \leq 15$ kgauss terms up to and including $H^3$ are important. Contributions from $H^4$ also play a small role. This effect has been mapped out by measurements of longitudinal and transverse voltages on Sb single-crystal rods, as a function of $H$ and of the directions of the primary current and of the magnetic field with respect to crystal axes. The results are described in terms of a set of phenomenological coefficients of various products of the magnetic field components, compatible with the crystal symmetry of Sb. For $H$ in kgauss, the ratio of second- and third-power coefficients to the first-power Hall constants is of the order of $10^{-2}$ and $10^{-4}$, respectively, although not all of the higher-order coefficients are of the same magnitude.

* This work has been supported in part by the Office of Naval Research.

**L5. Magnetoresistance in Germanium at Low Temperatures.*** F. J. DARNELL AND S. A. FRIEDBERG, *Carnegie Institute of Technology*.—Magnetoresistance measurements have been carried out for oriented single crystals of $n$- and $p$-type germanium at temperatures down to 4.2°K. Magnetic fields up to 5400 gauss were applied in the longitudinal direction and in various transverse directions with respect to the current. The region in which $(\Delta\rho/\rho) \propto H^2$ is quite small, being exceeded at 77°K, for example, by applied fields of a few hundred gauss and by still smaller fields at lower temperatures. The effects observed above nitrogen temperatures are similar to those reported by Pearson and Suhl.[1] For high-purity $n$-type material the results down to 20°K are in reasonable accord with the strong-field theory of Abeles and Meiboom[2] allowing only for scattering by lattice vibrations. The very large effects observed at 4.2°K may be treated with the same theory if impurity scattering is included. The applicability of this theory to $p$-type material at these temperatures will be considered.

* Work supported in part by the National Science Foundation and the Office of Naval Research.
[1] G. L. Pearson and H. Suhl, Phys. Rev. **83**, 768 (1951).
[2] B. Abeles and S. Meiboom, Phys. Rev. **95**, 31 (1954).

**L6. Conductivity of Nickel Oxide as a Function of Temperature and Surrounding Atmosphere.*** ROBERT LINDSAY AND JOHN J. BANEWICZ, *Southern Methodist University*.—The electrical conductivity of NiO has been determined from temperatures of 200°C to 1000°C in atmospheres containing oxygen at partial pressures of 3 to 760 mm of Hg. Samples prepared by two different methods were used. One sample was made by sintering NiO prepared by the decomposition of $Ni(OH)_2$. The second sample was formed by treating nickel metal in air at 1000°C. Both samples had platinum potential probes embedded in them. For each atmosphere, reproducible curves were obtained. In all temperature regions the $\log\sigma$ *vs* $1/T$ plot was approximately linear. Characteristic temperatures were noted for each atmosphere at which the slopes of the plots changed. In the upper temperature regions the conductivity of NiO was found to increase with increasing oxygen pressure in the manner noted by Baumbach and Wagner.[1]

* Assisted by a grant from the Research Corporation.
[1] Baumbach and Wagner, Z. Physik. Chem. B24, 59 (1934).

**L7. Electronic Interaction of Imperfections in Semiconductors and Insulators.** R. L. LONGINI, *Westinghouse Research Laboratories*.—The concentrations of electrons and holes in semiconductors and insulators are modified by the introduction of impurities or of vacancies into an otherwise perfect crystal. As a result of this modification, certain electronic energies are added to the free energy of solution of these "particles." In particular, if a crystal becomes very $n$-type, the $p$-type impurities or vacancies can go into the crystal much more easily than in the intrinsic material and furthermore, $n$-type impurities have greater difficulty in entering the crystal. Similarly, $p$-type impurities or vacancies in large quantity reduce the ease with which further $p$-type impurities or vacancies can come into the crystal and increase the solubility of $n$-type impurities. The extent of this effect is shown to depend drastically on the energy gap, such that in insulators almost any excess of $n$-type impurities will cause either $p$-type impurities or vacancies to go into the lattice. This electronic interaction also affects the diffusion of substitutional impurities in such a way that $n$-type impurities will have a tendency to diffuse more rapidly than $p$-type.

**L8. Comparison of the Condon and the Adiabatic Approximations for an Impurity Center.** JORDAN J. MARKHAM, *Zenith Radio Corporation*.—For most purposes wave functions of an electron trapped at an impurity in a crystal are approximated by the product of two functions, one involving the lattice coordinates and the other the position of the electron. The electronic function may be determined for the equilibrium position of the lattice (Condon approximation) or one may assume that the electronic wave function continuously adjusts itself to the instantaneous position of the lattice (adiabatic approximation). The first approach underestimates the kinetic energy and overestimates the potential energy, while the second does just the reverse. The author has compared the two approximations using the variational principle. Although the formal treatment is quite general and includes all the effects for harmonic vibrations, the actual terms were evaluated for a simple model. The calculations show that for extremely shallow traps the Condon approximation is slightly superior while for deep traps the adiabatic should be used. For traps of depths less than 0.2 ev the methods are essentially equivalent; in any of these calculations, other approximations are made and they are of greater importance than the slight difference between the properly used Condon or adiabatic approximations.

**L9. A Combined Tight Binding and Perturbation Theory of Graphite $\pi$ States.** J. C. SLONCZEWSKI AND P. R. WEISS, *Rutgers University*.—Apparently the Fermi surface of graphite lies in the neighborhood of the $\pi$-band zone edges parallel to the hexagonal $z$-axis. A special method is used to estimate the energies in this region. The dependence of energy on $k_z$ is obtained by a tight binding method in which a Bloch sum is formed of solutions of the isolated layer approximation. The dependence of energy on $k_x$ and $k_y$ is obtained by perturbing the states whose wave vectors lie on the edge of the zone with the operator $\hbar^2/im(k_x\partial/\partial_x + k_y\partial/\partial_y)$. Here $k_x$ and $k_y$ are measured from the zone edge. This method yields simple relations between variable $x$- and $y$-components of tensor mass and certain "vertical" energy gaps. Interaction between second-nearest layers results in band overlap. Spin-orbit coupling is found to modify the results stated.

**L10. Propagation and Plasma Oscillation in Semiconductors.*** BENJAMIN LAX AND LAURA M. ROTH,† *Lincoln Laboratory.*—The classical magnetoionic theory[1] can be extended to semiconductors whose energy surfaces in the Brillouin zone are ellipsoidal or warped spherical surfaces possessing cubic symmetry. The conductivity tensors in either case are evaluated in a coordinate system in which the magnetic field is along one of the axes. The tensor is substituted in Maxwell's equations and solutions are obtained for the propagation constant in terms of an effective conductivity. The effective conductivity is tabulated for the ellipsoidal models for longitudinal and transverse propagation for the high symmetry [001], [110], and [111] crystal directions. Polynomial equations for the plasma oscillation frequencies are obtained for each of these cases when the propagation constant is equated to zero. The theory is being extended to warped surfaces since approximate expressions for the conductivity tensor have been obtained in this case.[2] Modifications of the results when depolarizing effects[3] have to be taken into account will also be discussed.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
† Now at Harvard University, Cambridge, Massachusetts.
[1] E. V. Appleton, U.R.S.I. Reports, Washington (1927).
[2] H. J. Zeiger (private communication).
[3] C. Kittel, Physica (to be published).

**L11. Radiation Effects in Gallium Antimonide.** J. W. CLELAND AND J. H. CRAWFORD, JR., *Oak Ridge National Laboratory.*—The conductivity of *n*- and *p*-type GaSb[1] of high-carrier concentration decreases monotonically under fast neutron irradiation and approaches saturation before any intrinsic behavior is observed. The removal rate of current carriers is approximately equal for both types of material for high carrier concentrations and is quite temperature dependent. Measurements of the Hall constant after exposure indicate the production of electron traps in *n*-type and hole traps in *p*-type and low-temperature (~120°C) heating indicates that some of these irradiation produced traps are thermally annealable. Extended high-temperature (~500°C) vacuum anneal, however, increases greatly the acceptor concentration of irradiated *p*-type specimens but does not markedly alter the acceptor concentration of unirradiated companion samples. A similar decrease in effective donor concentration of irradiated *n*-type material permits the formation of samples with a lower initial-carrier concentration. Reirradiation then indicates that the removal rate of current electrons in *n*-type material is not dependent upon initial-electron concentration. The removal rate of holes in *p*-type material, however, decreases rapidly for material of lower initial-hole concentration.

[1] We are indebted to Dr. Raymond L. Smith of the Franklin Institute for the *p*-type samples and to Dr. H. P. R. Frederikse of the National Bureau of Standards for the *n*-type samples used in these experiments.

## FRIDAY MORNING AT 10:00

## Continental Room

## (B. L. CRAWFORD presiding)

## *Chemical Physics*

**LA1. Improved Symmetrized Cell Theory of Liquids.** J. DAHLER AND J. O. HIRSCHFELDER, *University of Wisconsin.*—To obtain practical results from the cell theory of liquids, it seems necessary to assume a simple symmetry for the distribution of a molecule about its lattice site. This is accomplished by replacing the interaction of the molecule with its neighbors by some "suitably averaged" interaction. In the Lennard-Jones and Devonshire treatment, the pair interaction is replaced by its spatial average. We find that a Boltzmann-type average is much more satisfactory. For an assumed symmetry of the distribution, our procedure provides an extension of Kirkwood's theory such that the resulting integral equation for the distribution function can be solved by numerical methods. We have found the function $L$ defined by the double surface integral,

$$\iint_{\sigma_1\sigma_2} f(\rho,r_1,r_2,R)\,d\sigma_1 d\sigma_2 \Big/ \iint_{\sigma_1\sigma_2} d\sigma_1 d\sigma_2 = \int_{\rho_{\min}}^{\rho_{\max}} f(\rho,r_1,r_2,R)L(\rho/R,r_1/R,r_2/R)/R\,d\rho$$

to be extremely useful. Here, $r_1$ and $r_2$ are the radii of two spheres, $R$ the separation of their centers, $\rho$ the separation of points on the two spheres, and $f$ an arbitrary function of its arguments. $L$ is found to be a quadratic function of $\rho$, different for various subranges of the interval $(\rho_{\min},\rho_{\max})$. For a variety of physical problems such as x-ray and electron diffraction, $L$ may have application.

**LA2.** (Abstract withdrawn.)

**LA3. Temperature-Pressure-Structure Effects on the Viscosity of Several Higher Hydrocarbons.*** D. A. LOWITZ, W. WEBB, AND R. W. SCHIESSLER, *The Pennsylvania State University.*—The viscosity of several very pure high molecular

weight hydrocarbons has been determined at six temperatures ranging from 100°F to 275°F and at pressures ranging from 15 to 50 000 psi by use of a rolling-ball viscometer. For three of the hydrocarbons for which pressure-density data were not available, the density was determined over the same limits of pressure and temperature by use of a flexible bellows piezometer. The group varies in molecular weight from 240 to 429 and comprises several structural families of chain to ring and cyclohexyl to benzenoid ring structure. When the pressure-viscosity data are plotted in the form $\log\eta/d$ *vs* $[(v_0/v)^4 - K(v_0/v)^2]$, where $\eta$ is the viscosity at pressure $P$, $v_0$ is the specific volume at atmospheric pressure, $v$ is the specific volume at $P$, and $K$ is a constant chosen for each compound, it is found that reasonably good straight lines are obtained.

* Research supported in part by America Petroleum Institute Project 42.

**LA4. A Study of the Compressions of Several High Molecular Weight Hydrocarbons.*** W. G. CUTLER, R. W. SCHIESSLER, AND W. WEBB, *The Pennsylvania State University.*—Using the Bridgman sylphon bellows technique, compressions for several very pure liquid hydrocarbons have been measured to pressures as high as 150 000 psi at 100°F, 140°F, 175°F, 210°F, 239°F, and 275°F. The hydrocarbons have a molecular weight range of 170 to 351 and include normal paraffins, cycloparaffins, fused ring aromatics, and fused ring napthenes. The Tait equation, $v_0 - v = C\log(1+P/B)$, provided a good empirical fit for the isotherms. In the above equation $C$ and $B$ are constants, $v$ is the specific volume at pressure $P$, and $v_0$ is the specific volume at atmospheric pressure. The Hudleston relation, $\log[v^1P/(v_0^1 - v^1)] = a - b(v_0^1 - v^1)$, where $a$ and $b$ are constants and other symbols have the same meaning as above, has also been examined. Isobars and isochores have been drawn and studied over the full range of pressure and temperature. The effect of molecular structure on the compressibility of the hydrocarbons has been examined.

* Part of the work of Research Project 42 of the American Petroleum Institute.

**LA5. Statistical Mechanics of Isotopic Systems with Small Quantum Corrections.*** JACOB BIGELEISEN, *Brookhaven National Laboratory.*—The differences in the thermodynamic properties of isotopic molecules, which can be described by the first quantum correction ($u^2/24$ law), depend on the difference in the reciprocal masses of the atoms in the molecule, and are, therefore, independent of all masses except for those atoms isotopically substituted. This theorem provides a rigorous proof of the rule of the geometric mean for gaseous molecules. The theorem shows that the partition function ratio for double labelled molecules is equal to the appropriate ratio for single labelled molecules. The rule of the geometric mean for the vapor pressures can be derived using the assumption that the internal energy states are the same in the liquid and gas. The vapor pressures of the liquid hydrogens can be calculated in good agreement with experiment from the vapor pressures of any two, e.g., $H_2$ and HD. The partition function ratios for molecules of the type $XY_n$, $XY_{n-1}Y'$ can be expressed in terms of the masses $Y$ and $Y'$ and the symmetrical stretching frequency. This permits an evaluation of the experimental data on the fractionation of $H_2O^{18}$ and $H_2O^{18}$ by cations in terms of the breathing frequency. The results are in agreement with predictions from an electrostatic model.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

**LA6. Derivation of a Quantum-Statistical Transport Equation for Dilute Gases.** A. W. SÁENZ, *Naval Research Laboratory.*—We have derived a quantum-statistical transport equation for dilute gases composed of particles of spin zero using the properties of Wigner distribution functions (d.f.'s), Kirkwood's method of time averaging over a suitable interval $\tau$,[1] and the formal time-dependent scattering theory. Our main assumptions may be stated roughly as follows: (i) the hypothesis of binary collisions; (ii) the effect of the statistics need only be taken into account for pairs; (iii) the d.f.'s are slowly varying over suitable microscopic regions and the time-averaged d.f.'s depend only secularly on time; (iv) an assumption of molecular chaos appropriate to bosons. The collision terms of our equation of transport contain an exact cross section: they reduce to those given by Kirkwood and Ross[2] when we evaluate this cross section according to the first Born approximation. The relation of our work to that of Mori and Ono,[3] Ono,[4] and Kirkwood and Ross[2] will be mentioned.

[1] J. G. Kirkwood, J. Chem. Phys. **14**, 180 (1946); **15**, 72 (1947).
[2] J. G. Kirkwood and J. Ross, J. Chem. Phys. **22**, 1094 (1954).
[3] H. Mori and S. Ono, Progr. Theoret. Phys. **8**, 327 (1952).
[4] S. Ono, Progr. Theoret. Phys. **12**, 113 (1954).

**LA7. Einstein-Bose Gas Below the Critical Temperature.** J. FORD AND T. H. BERLIN, *Johns Hopkins University.*—The canonical partition function for an ideal Einstein-Bose gas is often expressed as a contour integral and then evaluated by the method of steepest descent. It had previously been thought that this method failed below the critical temperature, since the saddle point then became congruent with a singularity of the integrand. This difficulty can be overcome by using an indented contour. The partition function thus evaluated yields the same expressions for thermodynamic variables as are obtained by other procedures.

**LA8. Statistical Mechanical Calculation of the Data of State of the Helium Isotopes at Intermediate Temperatures and Densities.*** ABRAHAM S. FRIEDMAN AND IRWIN OPPENHEIM, *National Bureau of Standards.*—Series expansions for the quantum mechanical partition functions, distribution functions, and thermodynamic functions, which were developed previously,[1] have been applied to the computation of the quantum mechanical compressibility factors for the isotopes of helium. DeBoer's quantum corrected values of the Lennard-Jones 6–12 intermolecular force constants were used, and the differences in compressibility factors, $Z_{He^4} - Z_{He^3}$ and $Z_{He^4} - Z_{He^6}$ were computed over a wide temperature and pressure range.

* Supported in part by the U. S. Atomic Energy Commission, Division of Research.
[1] I. Oppenheim, Bull. Am. Phys. Soc. **29**, No. 8, 10 (1954), abstract D6.

**LA9. Ideal Gas Thermodynamic Functions of the Isotopic Hydrogen Sulfides.*** LESTER HAAR, JOE C. BRADLEY, AND ABRAHAM S. FRIEDMAN, *National Bureau of Standards.*—The ideal gas thermodynamic functions for $H_2S$, $D_2S$, $T_2S$, HDS, HTS, and DTS were calculated from molecular data. The recent spectroscopic data for $H_2S$ and $D_2S$ by Allen[1] were employed. The zero-order frequencies and the moments of inertia of the other isotopes were calculated from the $H_2S$ and $D_2S$ data. The partition functions are obtained in closed form. The calculations include high-temperature corrections for vibrational anharmonicity, rotation-vibration coupling, centrifugal stretching, and a low-temperature correction for nonclassical rotation, in addition to a correction for the ortho-para effect.[2] The statistical calculations were performed on the National Bureau of Standards digital computer—SEAC. Tables of $C_p^0/R$, $(H^0 - E_0^0)/RT$, $-(F^0 - E_0^0)/RT$, and $S^0/R$, have been calculated at close temperature intervals from 50°–5000°K.

* Supported in part by the U. S. Atomic Energy Commission, Division of Research.
[1] H. C. Allen, Jr. (private communication).
[2] H. W. Woolley (in preparation).

## FRIDAY MORNING AT 10:00

Exhibit Hall II

(U. FANO presiding)

### *Invited Papers from the National Bureau of Standards*

**M1. Direct Measurement of Negative-Ion Affinities.** L. M. BRANSCOMB, *NBS.* (30 min.)
**M2. The Theory of Electron Penetration.** L. V. SPENCER, *NBS.* (30 min.)
**M3. Elastic Scattering of Photons from 5 to 30 Mev.** E. G. FULLER, *NBS.* (30 min.)
**M4. Nuclear Orientation at Low Temperatures.** ERNEST AMBLER, *NBS.* (30 min.)

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## FRIDAY AFTERNOON AT 2:00

Main Ballroom

(E. SEGRÈ presiding)

### *Scattering and Polarization of Nuclei*

**N1. Polarization Effects in Proton-Proton Scattering at 210 Mev.*** EMANUEL BASKIR,† JOHN TINLOT, AND SIDNEY SPITAL, *University of Rochester.*—Measurements have been made of the angular dependence of proton polarization produced by $p$-$p$ collisions at 210-Mev laboratory energy. A highly-polarized beam of protons, produced by scattering from a carbon or a beryllium target at $15°\pm1°$, is scattered from a second target and is counted in a multicrystal telescope mounted on a rotatable arm. The mean beam energy is $210\pm2$ Mev; full width at half maximum, $10\pm2$ Mev. Both polyethylene and liquid hydrogen second targets have been used to cover the barycentric angular range from 20° to 90°. Preliminary measurements have also been made at lower energies, e.g. $130\pm10$ Mev and indicate agreement with results obtained at Harwell.[1] A least squares fit to the 210-Mev data will be presented, and comparison made to results obtained at other energies.

* Work supported by the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
[1] Dickson and Salter, Nature **173**, 946 (1954).

**N2. Polarization of 210-Mev Protons Elastically Scattered from Carbon.*** W. G. CHESNUT, E. M. HAFNER, AND R. HARDING, *University of Rochester.*—The angular dependence of scattering asymmetry has been measured using a carbon scatterer in the highly-polarized external 210-Mev proton beam from the Rochester cyclotron. Data were taken simultaneously in several energy intervals near the elastic peak by means of seven scintillation counters and differential absorbers mounted on the rotating telescope arm. This system allows several checks upon success in separating elastically scattered protons from those which leave the carbon nucleus in its 4.4-Mev excited state. The results indicate small contamination of inelastically scattered protons in the count obtained for the channel of highest energy. The observed asymmetry that is believed to represent principally elastic scattering reaches a maximum at approximately 17°, shows a decided dip to a minimum at 30°, and then rises sharply up to 37.5° in the laboratory which is the largest angle at which measurements have so far been made. Estimates of the absolute values of $(d\sigma/\partial\omega)_R$ and $(\partial\sigma/\partial\omega)_L$ will be given.

* Work supported by the U. S. Atomic Energy Commission.

**N3. Phase-Shift Analysis of 210-Mev Proton Polarization.*** E. M. HAFNER AND W. CHESNUT, *University of Rochester.*—Attempts have been made to describe the results of the preceding paper in terms of sets of 40 phase shifts for partial waves up to $l=10$. The optical model of Taylor,[1] and the $l\cdot s$ potential suggested by Fermi[2] and developed by Sternheimer,[3] were used as guides in this work. A spin-independent potential intermediate between a square well and a harmonic-oscillator well, combined with a harmonic-oscillator spin-dependent potential, produce a qualitative description of the results. The phase shifts can then be perturbed in such a way as to give an accurate fit to the data up to $\vartheta=30°$, but they predict stronger polarization at larger angles than is actually observed. Possible causes of this discrepancy will be discussed.

* Work supported by the U. S. Atomic Energy Commission.
[1] T. B. Taylor, Phys. Rev. **92**, 831 (1953).
[2] E. Fermi, Nuovo cimento **11**, 407 (1954).
[3] R. M. Sternheimer, Phys. Rev. **95**, 587 (1954).

**N4. Negative Pressure Pentane Bubble Chamber Used in High-Energy Experiments.*†** RICHARD J. PLANO‡ AND IRWIN A. PLESS, *The University of Chicago.*—A negative pressure isopentane bubble chamber has been constructed and used to examine high-energy proton interactions with hydrogen and carbon. The sensitive fluid is contained in an all glass system with inside dimensions $13\times13\times27$ mm. The flat walls were polished to allow precision photography. The chamber was operated at a temperature of 127°C, compressed with a positive pressure of 40 atmospheres, and expanded to a negative pressure of 2.5 atmospheres. The recycling time was typically two seconds and included the following operations. The chamber was expanded to the desired negative pressure after which the cyclotron was pulsed. The incident protons passed through a counter telescope in front of the chamber, giving a coincidence pulse which was delayed 4 microseconds and used to trigger a light flash of duration 3/4 microsecond. Two 35-mm cameras were used in a 90° stereo arrangement to permit maximum accuracy in angular measurements.

* Abstract placed in this session at special request.
† Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
‡ National Science Foundation Predoctoral Fellow.

**N5. A Study of 456-Mev Proton Interactions with Hydrogen and Carbon.*** IRWIN A. PLESS AND RICHARD J. PLANO,† *The University of Chicago.*—The negative pressure bubble chamber described in the preceding abstract was used to investigate high-energy proton interactions with hydrogen and carbon. Proton-proton elastic scatterings are distinguished from proton-carbon interactions down to a laboratory angle of 4°. The accuracy on our angular measurements exceeds 1°. A typical hour of scanning will reveal on the order of one proton-proton scattering, three elastic proton-carbon scatterings, and five proton-carbon inelastic reactions. Total cross sections obtained are in good agreement with published data. The carbon-star prong distribution will be presented, as will

histograms describing the angular distribution of elastic proton-proton, elastic proton-carbon, and quasi-elastic proton-nucleon scatterings.

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.

**N6. $P-P$ Interactions at 3 Bev.*** A. KERNAN† AND R. CESTER, *University of Rochester.*—Ilford G-5 emulsions were exposed to the internal beam of the Brookhaven proton synchrotron in order to study proton-proton interactions in emulsion; the incident beam energy was determined to be 3 Bev by the relative scattering technique.[1] The plates were examined under high magnification using the along-the-track scanning technique. Only those events were accepted for analysis having an even number of prongs (exclusive of the incident proton) and satisfying certain kinematical criteria necessary to insure their compatibility with an initial nucleon-nucleon interaction; i.e. either with an H-atom of the emulsion or a proton of an emulsion nucleus. Of twenty events completely analyzed to date 3 are elastic scatterings, 10 represent single $\pi$-meson production and 7 represent multiple $\pi$ production ($\geq 2\pi$ mesons). Additional data will be presented and the cm angular distribution for the single $\pi$ production will be given. The data obtained for the inelastic events will be compared with current theoretical predictions.

* This research supported in part by the U. S. Atomic Energy Commission.
† American Association of University Women Fellow.
[1] M. Koshiba and M. F. Kaplon, Phys. Rev. 97, 193 (1955).

**N7. Elastic Scattering of 40-Mev Alpha Particles from Heavy Nuclei.*** HARVEY E. WEGNER, R. M. EISBERG, AND G. IGO, *Brookhaven National Laboratory.*—Recent experiments[1] on the elastic scattering of alpha particles from heavy nuclei have been successfully interpreted by several theoretical methods. In this experiment we have measured the angular distribution for the elastic scattering of 40-Mev alpha particles from Th, Pb, Au, Pt, W, and Ta, in order to provide additional data which may be used to differentiate between these methods. The scattered particles were detected, at laboratory angles ranging from 20 to 55 degrees, by a thin NaI (Tl) crystal mounted on a Dumont 6292 photomultiplier tube. The elastically-scattered alpha particles were separated from the other particles by pulse height analysis. Slides will be shown giving the ratio of the observed cross section to the Coulomb cross section as a function of laboratory angle. This ratio decreases approximately exponentially for scattering angles greater than a certain critical angle. In order to provide a simple comparison of the results of this experiment with previous data, slides will be shown giving the ratio of the observed cross section to the Coulomb cross section as a function of parameters which are common to all three experiments, such as the momentum transfer or the apsidal distance of the classical trajectory.

* This work has been carried out at the Brookhaven 60-inch cyclotron under the auspices of the U. S. Atomic Energy Commission.
[1] G. W. Farwell and H. E. Wegner, Phys. Rev. 95, 1212 (1954).

**N8. Absolute Angular Distribution of 20-Mev Protons Elastically Scattered by Oxygen and Nitrogen.*** RICHARD H. CHOW† AND BYRON T. WRIGHT, *University of California, Los Angeles.*—The absolute angular distributions of 20-Mev protons scattered elastically by $O^{16}$ and $N^{14}$ were determined using the externally deflected beam of the U.C.L.A. synchro-cyclotron. The scattered protons were detected with angular resolution of about $\pm 1.3°$ by an NaI (Tl) scintillation detector with about 1.5 percent energy resolution full width at half maximum. The low-counting rate at 60° and beyond for $O^{16}$ was overcome by scattering from a solid LiOH target about 6½ mgm per cm² thick and resolving the various groups of elastically-scattered protons. The relative distribution so obtained was normalized at 60°. For $N^{14}$, at 45° and beyond the protons were scattered from the gas confined at one atmosphere pressure in a small cylinder constructed of 0.0005-in. duraluminum and 0.001-in. "Mylar" polyester foils. The various methods were cross checked and agreed within statistics. The resultant angular distributions for the two elements were similar but the minima in the oxygen curve were slightly deeper. In terms of the optical model this feature can be interpreted qualitatively as less absorption in the case of $O^{16}$.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the Atomic Energy of Canada Limited, Chalk River, Ontario.

**N9. Elastic Scattering of 17-Mev Protons by Nuclei.*** G. SCHRANK, *Princeton University.*—Angular distributions of 17-Mev protons elastically scattered by Ta, W, and Bi have been obtained. Data was taken every five degrees from 20° to 172° with an absolute standard-deviation error of three percent. A five-parameter optical model, based on a complex potential with a fuzzy boundary, and including a nuclear spin-orbit term of the Thomas type, is used in an attempt to fit the data. In addition, angular positions of the second diffraction minimum for about twelve light nuclei have been experimentally determined with an accuracy of about 0.2 percent. The usefulness of this data in observing local variations in nuclear "radii" will be indicated.

* Work supported by the U. S. Atomic Energy Commission and The Higgins Fund.

**N10. Differential Cross Sections for Elastic Scattering of Nitrogen by Nitrogen.** H. L. REYNOLDS AND A. ZUCKER, *Oak Ridge National Laboratory.*—The angular distribution of nitrogen elastically scattered by nitrogen was measured for laboratory energies from 13 to 22 Mev. A gas target at a pressure of approximately ½ cm of mercury was used with Ilford D-1 nuclear emulsions as the particle detectors. The incident beam was collimated to $\pm 1$ deg while the angular acceptance of the detector was $\pm 1$ deg. Absolute values for the differential cross sections were obtained by normalizing the angular distributions to the calculated Coulomb cross sections at small angles, where nuclear forces did not contribute to the cross sections. At the lower energies the interference term in the Mott Coulomb-scattering formula clearly appears, illustrating the known spin and statistics of nitrogen. As the energy is increased the differential cross section falls below that predicted for Coulomb scattering because of the increasing importance of the nuclear interaction. At 22 Mev the differential cross section at 45 deg in the laboratory system is about ½ of the Coulomb cross section, with the deviation from the Coulomb cross section beginning at about 25 deg.

**N11. Energy Levels of $Na^{21}$.*†** W. HAEBERLI, *University o Wisconsin and Duke University.*—A phase-shift analysis of $Ne^{20}(p,p)Ne^{20}$ cross-section data[1] has been performed. Resonance phase shifts have been extracted by a new method which will be discussed. The analysis indicates resonances with the following resonant energies ($E_p$, Mev), total widths (kev), angular momenta and parities: 1.81, 180, $3/2^-$; 1.953, 6, $5/2^+$; 2.135, 17, $3/2^+$; 3.176, 110, $1/2^+$; 3.566, 25, $3/2^-$; 3.828, 6, $5/2^-$, or $7/2^-$; 4.28, 150, $3/2^+$, or $5/2^+$; corresponding to virtual states of $Na^{21}$ at 4.18, 4.31, 4.49, 5.48, 5.85, 6.10, and 6.53 Mev respectively. With the exception of the 6.10-Mev state, all these levels are found to have an elastic width $\Gamma_e > 0.7\Gamma$. An anomaly in the cross section observed at $E_p = 2.7$ Mev cannot be analyzed in terms of a single resonance. Also unassigned so far is a narrow resonance at $E_p = 3.552$ Mev ($\Gamma \sim 2$ kev) and a resonance with a small elastic width ($\Gamma_e < 0.1\Gamma$) at $E_p = 3.42$ Mev ($\Gamma \sim 20$ kev).

* Abstract placed in this session at special request.
† This work was supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
[1] Haeberli, Galonsky, Goldberg, and Douglas, Phys. Rev. 91, 438 (1953).

FRIDAY AFTERNOON AT 2:00

Exhibit Hall I

(E. O. SALANT presiding)

## *Mostly Hyperons and Heavy Mesons*

**P1. Production of Heavy Mesons at the Bevatron.*** L. T. KERTH, D. H. STORK, R. W. BIRGE, R. P. HADDOCK, AND M. N. WHITEHEAD, *University of California, Berkeley.*—Heavy mesons produced at 90° to the 5.7-Bev proton beam at the Berkeley bevatron have been focused by quadrupole magnets and deflected into a shielded region by means of an analyzing magnet. The target was copper, ¼ in. high and 1 in. in the beam direction. The distance from target to image was nine feet and the vertical and horizontal magnifications were 2.5 and 0.6, respectively. The focusing characteristics and momentum dispersion were investigated by placing nuclear plates at the image and determining the range and spatial distributions of protons produced at the target. A small emulsion stack has been exposed to 135 Mev positively charged $K$'s. The processed emulsions were scanned by searching for nonminimum tracks and following each track to the end of its range. Background was sufficiently low so that 17 $K$'s with a single lightly ionizing secondary track and $3\tau$'s were found in 24 man-hours of scanning. On the basis of past experience this represents an increase in scanning efficiency of about two orders of magnitude.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**P2. β Decay of *K*-Mesons.*** G. YEKUTIELI, M. F. KAPLON, AND J. KLARMANN, *University of Rochester.*—Two events in emulsion have been observed that are interpretable as the decay of a $K$-meson into an electron and two neutral particles. In the first, the decay track is emitted at minimum ionization with an energy of 260 Mev; identification rests upon the fact that it loses 110 Mev in 4.6 cm with no change in ionization, an abnormal loss for a $\pi$ or $\mu$ meson but not for an electron. In the second, the secondary is emitted with 20 Mev at minimum ionization; in terms of known particles it must be an electron. For both particles the primary mass is $\sim$1000 $m_e$. In view of these and other recent observations on the $K$-electron decay[1] it now seems conclusive that a $K$-meson exists decaying into an electron and two neutral massless particles (this is implied by the first event above). It is thus interesting to inquire as to whether those $K$-decays giving a continuous electron or $\mu$ meson spectrum may not be alternate modes via a Fermi interaction. The branching ratio is of order unity and the lifetime $\sim 10^{-9}$ second assuming a universal Fermi interaction.[2] A survey of the observations on $K$-meson decay in emulsion shows that the data do not contradict this hypothesis.

* This research was supported in part by the U. S. Air Force through the Office of Scientific Research, Air Research and Development Command.
[1] Recent observations reported by G. Goldhaber and M. G. K. Menon at Fifth Annual Rochester Conference.
[2] A. M. L. Messiah (unpublished).

**P3. High-Energy Cosmic-Ray Soft Showers in Nuclear Emulsion.*** M. KOSHIBA AND M. F. KAPLON, *University of Rochester.*—A stack of stripped emulsion flown in Sky-Hook Balloons at 41° geomagnetic latitude has been scanned for high-energy soft showers. More than twenty cases of pure electron showers have been observed and analyzed for which the apparent origin consists of a single electron pair in emulsion. The nature of these showers (initial pair energy in the region of 10 Bev) as well as the initial cascade development has been investigated, with special attention to the trident process[1] in the early development. Most of these showers are consistent with the assumption that they originate from the conversion of the decay photons from locally produced $\pi^0$ mesons. However, there are a few anomalous cases[2] not easily reconcilable with our present knowledge.

* This research was supported in part by the U. S. Air Force through the Office of Scientific Research, Air Research and Development Command.
[1] M. Koshiba and M. F. Kaplon, Phys. Rev. **97**, 193 (1955).
[2] Schein, Haskin, and Glasser, Phys. Rev. **95**, 855 (1954); A. Debenedetti *et al.*, Nuovo cimento **12**, 954 (1954); and N. Dallaporta (private communication).

**P4. "*V*-Particles" in Nuclear Emulsion.*** J. KLARMANN, M. F. KAPLON, AND G. YEKUTIELI, *University of Rochester.*—Emulsion stacks are well suited for precise energy determinations and identification of relatively energetic charged particles (effective energy limit determined by stack size) since they can be stopped and their energy determined by range measurement while identification is assisted by the characteristics of the track terminus. Emulsion stacks should thus afford the most precise $Q$-value determinations for unstable particles if they can be detected and their decay fragments stop. We have searched for "$V$-particles" by tracing back trajectories of $\sigma$ mesons; for those events in which the meson originates from a 2-prong star, the other prong being an ending proton, we calculate a $Q$-value assuming decay of a neutral particle into a proton and $\pi^-$ meson. Very precise $Q$-values are reported for the $\Lambda^0$ decay in this way.[1] At present 12 $V$-particles selected this way in our laboratory give a spectrum of $Q$-values including 3 between 36.6 and 37 Mev and two with 30.3 and 30.5 Mev, respectively. The latter two (having no counterpart in cloud chamber investigations) suggest a possible background of simulated $V$-particles in emulsion coinciding with the $\Lambda^0$.

* This research was supported in part by the U. S. Air Force through the Office of Scientific Research, Air Research and Development Command.
[1] Nuovo cimento Suppl. **2**, 461 (1954). The data reported here seems deficient in low $Q$-values.

**P5. Comparison of Ionization-Range Methods of Mass Estimation.** F. W. O'DELL AND M. M. SHAPIRO, *Naval Research Laboratory.*—For charged particles which come to rest by ionization loss in nuclear emulsion, two principal methods of mass estimation based on the variation of ionization with residual range (I-R) have been employed: grain density *versus* range and mean gap length *versus* range. These methods are particularly applicable, respectively, to relatively long ranges (where the track is "grainy") and to short ones (where the track is dense). For the first method (gain density *vs* $R$) the subjectivity of counting grains in "blobs" has been circumvented by measuring blobs and employing the convention that the grain count for a blob is proportional to its length. This procedure yields high reproducibility and satisfactory mass evaluation. A third method, utilizing as an index of ionization the ratio of integrated blob length to gap length, has been explored for its possible applicability, especially at shorter ranges. This technique, as well as the other two, has been applied to protons, pions, and $K$-mesons with a view to comparing the precisions obtainable with the three I-R methods when comparable times are invested in measurement.

**P6. Stopped *K*-Mesons Observed near the Geomagnetic Equator.** B. STILLER, M. M. SHAPIRO, AND N. SEEMAN, *Naval Research Laboratory.*—Stacks of stripped emulsions were exposed to the cosmic rays at an atmospheric depth of 12 g/cm² and geomagnetic latitude 10°N. Application of scattering-

range and ionization-range measurements to 16 $K$-meson tracks,[1] as well as to calibration tracks of stopped protons and pions, shows that I-R methods are capable of greater precision for comparable effort and available track length than S-R. Mass histograms for the group of $K$-primaries exhibit "best values" somewhat lower than but compatible with the tau-meson mass. For those $K$-mesons which exhibit a single fast charged decay product, ionization and $p\beta$ values were obtained for secondary tracks of sufficient length. These results are employed to infer the relevance of the respective schemes $K_{\mu 2}\rightarrow\mu+\nu$ and $\chi\rightarrow\pi+\pi^0$ to those $K$-decays. Measurements of the star products arising from the capture of negative $K$-mesons are also reported. A "complete" positive-tau meson event, including the star origin and all three terminating pion secondaries, is analyzed.

[1] Seeman, Shapiro, and Stiller, Bull. Am. Phys. Soc. 30, No. 1, 63 (1955), abstract Z2.

**P7. Recent Results on $S$-Particles.*** H. DeStaebler, Jr., H. S. Bridge, B. Rossi, and B. V. Sreekantan, *M.I.T.*—Data concerning $K$-mesons observed to decay at rest in a multiplate chamber ($S$-events) are reported. The distribution of the secondary ranges clearly exhibits two peaks, one at about 75 g cm$^{-2}$ copper and another at about 45 g cm$^{-2}$ copper. The first group supports the two-body decay proposed by the Paris group: $K_{\mu 2}\rightarrow\mu+\nu$. The second group provides strong additional evidence for the $\chi$ meson originally proposed by the Bristol group. According to our results the neutral particle in this decay must be a $\pi^0$ meson *vis.*; $\chi\rightarrow\pi+\pi^0$. Since the secondary range distribution is not continuous it is improbable that an appreciable fraction of the secondary particles arise from a three-body decay process.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**P8. Timing Measurements on Penetrating Cosmic Ray Showers.*** Kenneth W. Robinson,† *Princeton University.*—Time delays in local penetrating cosmic-ray showers have been measured using scintillation and Čerenkov detectors and a chronotron. After correcting for background a single exponential decay curve is obtained corresponding to a mean lifetime of 8.00±0.72 millimicroseconds. These delayed events may be interpreted as decays of stopped $K$-mesons.[1] The background is analyzed into accidental and $\pi-\mu-e$ events and a ratio of $\pi^+$ to $K$ of 8 to 1 is obtained, uncorrected for relative detection efficiencies. An associated Geiger counter hodoscope gives an average particle multiplicity of 6 for the delayed events interpreted as $K$-particles. Preliminary analysis of the data obtained from an experiment in which the Čerenkov detectors were surrounded alternately with thin Pb plates and equivalent Al plates indicates that gamma rays are associated with some of these delayed events. Comparisons will be made with a similar previous experiment.[2]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation, Predoctoral Fellow.
[1] H. Bridge, Nuovo cimento 12, 81 (1954).
[2] L. Mezzetti and J. W. Keuffel, Phys. Rev. 95, 858 (1954).

**P9. Momentum and Ionization Measurements on Charged $V$-Particles.*** W. B. Fretter, E. W. Friesen, G. E. Kepler, and L. Lagarrigue, *University of California, Berkeley.*—We have made several direct measurements of the mass of the primaries of charged $V$-particles by ionization-momentum measurements in a cloud chamber[1] at sea level. We have also measured the momentum $p^*$ of the secondaries in the center of mass system. To make this calculation, we can use two independent methods. The first is to obtain the velocity of the primary directly from the ionization measurement. The second is to use the measured momentum and an assumed mass. One negative particle has a mass of 1150±140 electron masses. The $p^*$ for the secondary is 171±18 Mev/c for a $\mu$ meson and 165±18 for a $\pi$ meson, by the ionization method. If we assume that the mass of the primary is 955 $M_e$ we find $p^*=157$ ±16 for a $\pi$ secondary. This particle does not appear to be a $\pi^-$, $\theta^-$, or $K\mu^-{}_2$, but could be a $K\mu^-{}_3$. The ionization measurements on the secondaries indicate that most of them are light mesons and not electrons.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] W. B. Fretter and E. W. Friesen, Rev. Sci. Instr. (to be published).

**P10. Angular Correlations in $V^0$-Particle Decays.*** B. V. Sreekantan, A. Pevsner, and G. Sandri, *M.I.T.*—Thirty-four cases of neutral $V$-particles produced inside the plates of a multiplate cloud chamber, by charged primaries, have been analyzed to find whether there exists any correlation between the production and decay planes of neutral $V$-particles. In twenty-four cases the limits on the $Q$-values of the $V^0$-particles could be determined, and the particles could be identified as probable $\Lambda^0$'s. All these cases are inconsistent with $\vartheta^0$'s. In the remaining ten cases the $V^0$-particle could not be identified. The distribution of the dihedral angle between the production and decay planes, based on these thirty-four cases, appears to be consistent with an isotropic distribution and does not show any marked tendency for the two planes to be parallel. Several more cases of single $V$'s and a few cases of double ($V_0$, $V_0$), and ($V_0$, $V_{ch}$) are being analyzed. Data on all these cases will be presented.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**P11. Evidence for Charge Asymmetry of $V^\pm$-Particles.*** Y. B. Kim, J. R. Burwell, R. W. Huggett, and R. W. Thompson, *Indiana University.*—It was previously reported[1] that the $p_\nu$-distributions and the distributions of decay points in the chamber indicate a $V^\pm$ charge asymmetry. Further analysis indicates that the $V^-$-lifetime is of the order of $10^{-10}$ but might be as long as $10^{-9}$ second. The $V^+$-lifetime appears to be considerably longer. Although the statistics are limited, the $V^+$-events suggest a long lived $K^+\rightarrow(L^++\text{one neutral})$ of mass about 1000 $m_e$. The mean value of $p'$ for 3 $V^+$-events is 222±5 Mev/c, in excellent agreement with the $K_\mu$.[2] If a substantial number of $V^+$-particles[3] are $\theta^+$, the lifetime of $\theta^+$ is probably considerably longer than $\theta^0$. Although the statistics are limited, the $p_\nu$-distribution of $V^-$ does not suggest an isotropic[4] two-body decay process of a homogeneous group.

* Assisted by the Office of Ordnance Research and by a grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] Kim, Burwell, Huggett, and Thompson, Phys. Rev. 96, 229 (1954).
[2] Gregory, Lagarrigue, Leprince-Ringuet, Muller, and Peyrou, Nuovo cimento 11, 292 (1954).
[3] Hudson, Ballam, Arnold, Harris, Rau, Reynolds, and Trieman, Phys. Rev. 96, 1089 (1954).
[4] The Princeton group reports that $V^-$-secondaries are emitted backward in the C-M system (Rochester Conference, 1955).

**P12. Multiplicity Distribution of O+N$_p$ Stars.** D. T. King, *Naval Research Laboratory.*—A track-following method has been used to find 149 stars, comprised only of thin or gray tracks, in G5 emulsions which had been exposed to the cosmic radiation. The stars are selected according to the requirements that (1) at least two charged particles appear to emerge and (2) the ionization of all tracks corresponds to velocities exceeding ~0.3 c. These criteria describe collisions of fast incident particles with hydrogen nuclei or edge nucleons of heavier nuclei in the emulsion. Among these stars, 19 percent are attributable to doubly-charged primaries, 72 percent to singly-charged primaries and 9 percent show no charged primary. The distribution in the number $N$ of emergent tracks for the 107 stars of type O+N$_p$ will be discussed.

**P13. Analysis of Properties of Secondary Particles in Nucleon-Nucleon Collisions at Very High Energy.*** R. G. GLASSER, D. M. HASKIN, AND MARCEL SCHEIN, *University of Chicago.*—The momentum of the individual particles emitted in the "outer cone" of the *S*-star[1] was measured. This star has a primary energy of $2\times10^{13}$ ev. In addition a lower limit to the momentum of the particles in the "inner cone" was obtained. It was found that one of the particles in the inner cone had an energy of 50 Bev from track-to-track scattering. On transforming the trajectories of the tracks from the laboratory (*L*-) system to the center-of-mass (*C*-) system for the nucleon-nucleon collision, the inner cone becomes the forward cone and the outer cone the backward cone. These two cones have a half-angle of about 20° each in the *C*-system, assuming in the transformation that all particles are pions. The symmetry in the *C*-system is satisfactory under this assumption, but from the properties of the Lorentz transformation, it can be shown that the presence of proton-antiproton pairs would distort this symmetry and that the energy of such pairs would be appreciably greater than that of the pions. The results of this investigation are compared with theories of multiple meson production including those of Landau and Heisenberg.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Lord, Fainberg, and Schein, Phys. Rev. **80**, 970 (1950); R. G. Glasser and Marcel Schein, Phys. Rev. **90**, 218 (1953).

**P14. Further Investigations on the Photon Event.*** MARCEL SCHEIN, D. M. HASKIN, AND R. G. GLASSER, *University of Chicago.*—The high-energy photon event found in a pellicle stack exposed in the stratosphere above Texas in 1954[1] has been analyzed carefully. The longitudinal and radial distribution of pair origins has been accurately determined, providing evidence for the convergence of pair origins in a distance of several centimeters from the entry of the event into the pellicle stack. The angular spread of the event is estimated to be $2\times10^{-4}$ radian. Energy measurements from multiple scattering on most of the pairs will be presented. At very high energies track-to-track scattering was employed. Possible interpretations of the photon event will be discussed.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Schein, Haskin, and Glasser, Phys. Rev. **95**, 855 (1954).

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## FRIDAY AFTERNOON AT 2:00

## Burgundy Room

## (T. W. BONNER presiding)

## *Transmutation and Nuclear Energy Levels, II*

**PA1. The Angular Distribution of Protons from the $O^{16}(d,p)O^{17}$ Reaction as a Function of the Bombarding Energy.*** J. C. GROSSKREUTZ, *University of Texas.*—The distribution in angle of the protons from the $O^{16}(d,p)O^{17}$ reaction has been measured for incident deuteron energies of 2.4, 2.2, 2.0, 1.78, 1.6, 1.4, and 1.1 Mev. Two groups of protons corresponding to the ground and first excited states of the residual nucleus $O^{17}$ were detected using a thin CsI crystal and Du Mont 6291 photomultiplier tube mounted inside a 23-inch diameter scattering chamber. A number *vs* energy curve was taken for each proton group at 14 different angles between 5 and 160 degrees in the laboratory system. The results show that the stripping process takes place down to at least 1.1 Mev for the ground-state protons, while for the lower-energy group, the forward maximum has almost completely disappeared at that energy. Competition from compound nucleus formation is clearly evident, especially near resonances in the total yield of the reaction.[1] The data join smoothly the results of Van Patter *et al.*[2] who have investigated the reaction at energies above 2.6 Mev.

* Supported in part by the Office of Scientific Research, Air Research and Development Command.
[1] N. P. Heydenburg and D. R. Inglis, Phys. Rev. **73**, 230 (1948).
[2] Van Patter, Simmons, Stratton, and Zipoy, Phys. Rev. **96**, 825 (1954)

**PA2. Deuteron Capture by $O^{16}$.** J. W. BUTLER, *Naval Research Laboratory.*—The cross section for radiative capture of the deuteron by $O^{16}$ has been measured by bombarding a 0.05-mil NiO foil and counting the positrons from the residual $F^{18}$ nuclei. The positrons were counted with a 2-crystal coincidence counter actuated by the 2-annihilation quanta. The contribution of $F^{18}$ from the $O^{17}(d,n)F^{18}$ reaction was determined by bombarding a similar target enriched[1] to 0.89 percent $O^{17}$. The cross section for the $O^{16}(d,\gamma)F^{18}$ reaction is of the order of 10 microbarns at 1.7-Mev bombarding energy. The cross section for the $O^{17}(d,n)F^{18}$ reaction at the same energy is some 3000 times higher.

[1] The enriched $O^{17}$ was kindly supplied by Professor A. O. C. Nier.

**PA3. Gamma Rays from Proton Bombardment of $O^{18}$.*** EMMETT L. HUDSPETH, IRA L. MORGAN, AND JOSEPH T. PEOPLES, *University of Texas.*—A thin target of gaseous $CO_2$ enriched[1] 14 percent in $O^{18}$ has been bombarded with protons of energy 0.3 to 2.6 Mev. The gas was contained in a cell of 2 cm depth, and the proton beam entered through a 0.05-mil Ni foil. Target thickness was estimated as 20 kev for 2.0 Mev protons. A 1½ in.×1½ in. NaI(Tl) crystal detector was used with a 20-channel analyzer. The excitation curve for ground-state transitions shows seven resonances, indicating levels in $F^{19}$ tentatively evaluated as 8.49, 8.76, 9.65, 9.83, 10.04, 10.15, 10.22, 10.28, and 10.36 Mev. The first two levels are also known from $O^{18}(p,\alpha)$; these are the least intense of the levels found in the present work. The excitation curve shows a sudden drop at the $O^{18}(p,n)$ threshold. A pulse-height analysis has been made of gamma radiation produced at a bombarding energy of 2.20 Mev. It shows transitions to known excited states of $F^{19}$, in addition to ground-state transitions.

* Supported in part by the Office of Scientific Research, Air Research and Development Command.
[1] The enriched $CO_2$ was obtained from the Temple University Research Institute.

**PA4. Excitation Curve for $F^{19}(n,\alpha)N^{16}$.*** NORMAN A. BOSTROM, EMMETT L. HUDSPETH, AND IRA L. MORGAN, *University of Texas.*—The cross section for the reaction $F^{19}(n,\alpha)N^{16}$ has been measured as a function of neutron energy from 3.5 to 6.2 Mev. Neutrons were obtained by bombarding thin deuterium gas targets with deuterons from the University of Texas Van de Graaff generator. The energy spread

of the neutrons was approximately 25 kev at $E_d=1$ Mev. A ring of $CaF_2$ was irradiated with neutrons for a few seconds; the generator was then turned off and the 7.35-second activity of $N^{16}$ was followed for several half-lives. Fluctuations in the deuteron-beam current were corrected by use of a circuit of a type previously described.[1] Resonances for this reaction appeared at neutron energies of 4.17, 4.68, 5.04, 5.40, 5.59, 5.90, and 6.08 Mev. The apparent threshold for the reaction is 3.88 Mev, which is 2.31 Mev above the calculated threshold of 1.57 Mev. These results are consistent with a spin assignment of $2(-)$ to $N^{16}$. This reaction offers possibilities for detection of fast neutrons in the presence of intense gamma radiation.

* Assisted by the U. S. Atomic Energy Commission.
[1] S. C. Snowdon, Phys. Rev. **78**, 299 (1950).

**PA5. Some Energy Levels of $Na^{22}$.*** C. P. Browne and W. C. Cobb, *M.I.T.*—The $Mg^{24}(d,\alpha)Na^{22}$ reaction has been used to observe levels in $Na^{22}$ up to 3-Mev excitation. Thin targets of natural magnesium metal were bombarded with deuterons accelerated by the MIT–ONR electrostatic generator to energies of 5, 6, and 7 Mev. The energies of alpha particles emitted at 90 degrees to the incident beam were measured with the new broad-range spectrograph. Ten groups of alpha particles have been identified with this reaction. At 7-Mev incident energy, all ten groups appear on the nuclear track plate in a single exposure. Preliminary results give a ground-state $Q$-value of 1.954 Mev and excited states at 0.59, 0.89, 1.53, 1.94, 1.99, 2.22, 2.58, 2.98, and 3.07 Mev. The assignment of the group indicating a level at 2.22 Mev is somewhat less certain than for the other groups. At 6-Mev incident energy the groups leading to the ground state and first two excited states have approximately equal intensity. Of course, if the isotopic spin-selection rule holds, $T=1$ levels in $Na^{22}$ will not be observed with this reaction. The energy of the first state observed here agrees with the 593-kev gamma ray previously observed.[1] In view of the observed intensities, it is unlikely that this level is the expected low-lying $T=1$ level.[2]

* This work has been supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **93**, 351 (1954).
[2] S. A. Moszkowski and D. C. Peaslee, Phys. Rev. **93**, 455 (1954).

**PA6. Angular Distributions and Angular Correlations in $Mg^{24}(d,p)Mg^{25}$.*** R. M. Williamson and S. A. Cox, *Duke University*.—The yields as a function of deuteron energy (2–4 Mev) of the nine longest range proton groups resulting from the $Mg^{24}(d,p)$ reaction have been obtained at selected angles between 15° and 135°. The proton detector was a thin crystal scintillator having a resolution of 2.5 percent for 8-Mev protons. Strong interference effects are observed in the yield curves, especially at the angles of the stripping peaks. The observed angles of the stripping peaks near 4-Mev deuteron energy are in agreement with other data.[1] The angular correlation between protons and gammas from the 3.40-Mev ($L_{neutron}=1$) level in $Mg^{25}$ has been measured at several deuteron energies. The correlation predicted by stripping theory[2] is $W(\theta)=1-0.14\cos^2\theta$. The measured anisotropies range between 0 and +0.30, the latter chamber corresponding to the most strongly peaked proton angular distributions. The presence of an anisotropy confirms the assigned[3] spin of $\frac{1}{2}$ for this level. The sign of the anisotropy indicates that stripping theory may not be applied in this deuteron energy and target $Z$ region.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] P. M. Endt and J. C. Kluyver, Revs. Modern Phys. **26**, 95 (1954).
[2] Biedenharn, Boyer, and Charpie, Phys. Rev. **88**, 517 (1952).

**PA7. Gamma-Ray Cascades in $Al^{25}$.** A. E. Litherland, E. B. Paul, G. A. Bartholomew, and H. E. Gove, *Chalk River Laboratories*.—The decay schemes of gamma rays in $Al^{25}$ from the $Mg^{24}(p,\gamma)$ reaction at the five resonances in the range of proton energies 0.8 to 2.1 Mev have been established by coincidence measurements employing two 5 in. by 4 in. NaI (Tl) crystals and associated electronics. All the resonances except that at 1.49 Mev ($J=7/2-$) showed direct transitions to at least two of the lowest three states. The relative intensities of these primaries have been measured and compared with predicted theoretical values for single-particle transitions and in one case with the mirror reaction $Mg^{24}(n,\gamma)$.[1] In general the agreement is not very good. At two of the resonances cascades occur through levels which are themselves unstable against proton emission, while at the 1.49 Mev resonance (3.72 Mev in $Al^{25}$, $J=7/2-$) the strongest transition is via a level at 1.81 Mev in $Al^{25}$ rather than the $5/2+$ ground state.

[1] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **93**, 1260 (1954).

**PA8. Gamma Rays from Proton Bombardment of $Mg^{24}$.** E. B. Paul, G. A. Bartholomew, H. E. Gove, and A. E. Litherland, *Chalk River Laboratories*.—A thin (10 kev) target of separated $Mg^{24}$ isotope[1] has been bombarded by protons in the energy range 0.8 to 2.1 Mev using the Chalk River electrostatic generator. The emitted gamma-rays have been studied in a 5 in. diameter by 4 in. long NaI (Tl) crystal coupled to a Dumont K-1198 photomultiplier. The five resonances found by elastic proton scattering[2] in this region have been observed. By measuring the angular distribution of the ground-state proton capture gamma ray at the 1.49 Mev resonance, the spin of this $f$-wave[3] resonance is shown to be 7/2. The absolute yield of gamma rays has been measured at some of the resonances. At the 2.01 Mev resonance the absolute yield of the 1.38 Mev gamma-ray indicates the partial width for inelastic scattering may be as much as 25 percent of the total width.[3]

[1] Obtained from Atomic Energy Research Establishment, Harwell, England.
[2] Mooring, Koester, Goldberg, Saxon, and Kaufmann, Phys. Rev. **84**, 703 (1951).
[3] L. J. Koester, Phys. Rev. **85**, 643 (1952).

**PA9. Magnetic Analysis of Protons from $Al^{27}(d,p)Al^{28}$.** W. W. Buechner, A. Sperduto, and Marcos Mazari.* *M.I.T.*—In a previous investigation,[1] using 2-Mev deuterons, fifty proton groups from this reaction were measured and assigned to levels in $Al^{28}$ between the ground state and 6.31 Mev. In the present work, using higher bombarding energies, a broad-range magnetic spectrograph[2] has been used to study these groups and to extend the region of excitation investigated up to neutron binding in $Al^{28}$. The assignment of most of the observed groups to this reaction is based on the agreement of the $Q$-values measured in observations at 90 degrees with deuteron energies of 6 and 7 Mev and observations at 35 and 10 degrees using 7-Mev deuterons. The previous work has been confirmed in detail, and a number of new levels have been established. The spectrum is complex, with at least 100 well-resolved levels between the ground state and neutron binding (7.72 Mev). This work has been supported in part by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.

* On leave from the National University of Mexico.
[1] Enge, Buechner, and Sperduto, Phys. Rev. **88**, 963 (1952).
[2] Buechner, Browne, Enge, Mazari, and Buntschuh, Phys. Rev. **95**, 609 (1954).

**PA10. The $Si^{28}(p,p'\gamma)Si^{28}$ Reaction.** H. O. Cohn, J. K. Bair, J. D. Kington, and H. B. Willard, *Oak Ridge National Laboratory*.—Work with platinum target backings indicated a strong 1.8-Mev gamma ray when bombarded with protons from the ORNL 5.5-Mev Van de Graaff generator.

It has been shown that this is due to a thin surface contamination of silicon. The gamma rays are produced by inelastic scattering of protons by the first excited state of $Si^{28}$ at 1.78 Mev. A 3 in. × 3 in. NaI(Tl) crystal was used to detect the gamma rays. Yields of this reaction have been measured at 0° with respect to the protons from 1.8- to 4.7-Mev bombarding energy. Resonances were observed at $E_p = 3.11$ Mev ($\Gamma = 12$ kev), 3.35 Mev ($\Gamma = 11$ kev), 3.58 Mev ($\Gamma = 70$ kev), 3.71 Mev ($\Gamma = 40$ kev), 4.25 Mev ($\Gamma = 22$ kev), and 4.44 Mev ($\Gamma \cong 100$ kev, this may be a superposition of two broad levels). Excitation energies in the compound nucleus $P^{29}$ are 5.73, 5.96, 6.18, 6.31, 6.82, and 7.01 Mev, respectively.

**PA11. Gamma-Ray Resonances in the Reaction $Si^{29}(p,\gamma)P^{30}$.*** S. MILANI, JOHN N. COOPER, AND J. C. HARRIS, *Ohio State University.*—Both thick and thin targets of electromagnetically separated[1] silicon-29 have been bombarded with protons of energies between 300 and 1000 kev. In addition to the gamma-ray resonances reported by Endt, Kluyver, and Van der Leun,[2] prominent resonances were observed at proton energies of approximately 696, 727, 917, and 956 kev. Preliminary data reveal several other resonances at energies between 1000 and 1200 kev. Measurements by scintillation spectrometer of the gamma-ray energies from the 414-kev resonance show the decay is predominantly by a cascade with gamma rays of 5.9 and 0.7 Mev as reported by Kluyver *et al.* At the 696-kev resonance the gamma-ray energies suggest decay through the 0.7- and 2.0-Mev levels[3] with relatively weak transitions to the level at 1.4 Mev. At the 727-kev resonance strong decay through the 1.4-Mev level is indicated.

* Supported in part by the U. S. Atomic Energy Commission through a contract with the O. S. U. Research Foundation.
[1] Supplied by Oak Ridge National Laboratory.
[2] Endt, Kluyver, and Van der Leun, Phys. Rev. **95**, 580 (1954).
[3] Mandeville, Swann, Chatterjee, and Van Patter, Phys. Rev. **85**, 193 (1952).

**PA12. Gamma Rays from Proton Bombardment of Phosphorus.*** B. D. KERN AND L. W. COCHRAN, *University of Kentucky.*—The spectrum of the gamma rays from the proton bombardment of a thick phosphorus target has been obtained at several proton energies using a $1\frac{1}{2}$ inches in diameter × 1 inch in length NaI(Tl) crystal in a scintillation spectrometer. Gamma rays whose energies vary with the proton energy are identified at 12.0, 9.7, 7.0, and 7.5 (±0.2) Mev, at $E_p = 1.3$ Mev ($Q = 10.7$ Mev). Gamma rays whose energies do not vary with the proton energy are seen at 2.3 and 1.6 (±0.1) Mev, poorly resolved; the 1.6-Mev gamma ray is tentatively identified as arising from the $P^{31}(p,\alpha\gamma)Si^{28}$ reaction. The spectrum of only those gamma rays of lower energy which are in coincidence with higher-energy gamma rays has been obtained and shows considerably better resolution. In it, gamma rays are identified at 0.5 (annihilation radiation), 2.25, 2.56, and 4.40 (±0.05) Mev. Levels in $S^{32}$ are indicated at 2.25, 4.40, and 4.81 Mev, in reasonable agreement with earlier reports.[1,2]

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] R. H. Dicke and J. Marshall, Jr., Phys. Rev. **63**, 86 (1943).
[2] S. C. Snowdon, Phys. Rev. **87**, 1022 (1952).

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FRIDAY AFTERNOON AT 2:00

Continental Room

(J. E. MAYER presiding)

## *Division of Chemical Physics*

## *Symposium on Nonequilibrium Processes*

**Q1. Statistical Mechanics of Irreversible Processes.** ILYA PRIGOGINE, *Harvard University and Free University of Brussels.* (30 min.)

**Q2. Fluctuations and Irreversibility.** HERBERT CALLEN, *University of Pennsylvania.* (30 min.)

## *Business Meeting of the Division of Chemical Physics*

**Q3. Theory of Sound Dispersion in Dilute Gases.** MARK KAC, *Cornell University.* (30 min.)

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FRIDAY AFTERNOON AT 2:00

Exhibit Hall II

(E. P. WIGNER presiding)

## *Post-Deadline Papers, If Any*

FRIDAY AFTERNOON AT 2:00

NBS, East Building

(L. MARTON presiding)

## *Electron Physics*

**R1. An Ultra-High Vacuum Valve.*** D. G. BILLS AND F. G. ALLEN, *Harvard University.*—An all-metal vacuum valve with a minimum leakage conductance of $10^{-12}$ l/sec has been described by Alpert.[1] We have found, however, using an Alpert-type seal that reproducible conductances of $10^{-12}$ l/sec are difficult to obtain, the usual minimum value for a typical valve being about $10^{-10}$ l/sec. By completely confining the softer metal in the seal we have produced simplified and enlarged valves with conductances which are continuously variable from 1 l/sec to less than $10^{-14}$ l/sec. Presumably the conductance may be made as small as desired. All of the advantages of Alpert's design have been retained in the new design.

* Supported in part by the Office of Naval Research, the Signal Corps of the U. S. Army, the U. S. Air Force, and the Air Force Cambridge Research Center.

[1] D. Alpert, J. Appl. Phys. **24**, 860 (1953).

**R2. Ambipolar Diffusion in a Magnetic Field.** ALBERT SIMON, *Oak Ridge National Laboratory.*—Diffusion of ions in an arc plasma across a magnetic field is shown to be *not* ambipolar in character in most experiments. Owing to the highly anisotropic conductivity of the medium, the ions diffuse across the field at their own intrinsic rate. Space-charge neutralization is maintained by slight adjustment of the currents in the direction of the magnetic field lines. Previous experiments by Bohm, Burhop, Massey, and Williams[1] on calutron arcs had indicated a discrepancy of greater than $10^3$ between the experimental diffusion coefficient and the coefficient calculated by the usual ambipolar theory. This discrepancy is now resolved and no additional mechanisms, such as plasma oscillations, need be postulated. Both an intuitive and formal proof of the effect will be presented.

[1] A. Guthrie and R. K. Wakerling, *The Characteristics of Electrical Discharges in Magnetic Fields* (McGraw-Hill Book Company, Inc., New York, 1949), NNES I-5, Chapter 9.

**R3. A Possible Explanation of Moving Striations in Discharge Tube.** SATOSI WATANABE AND NORMAN OLESON, *U. S. Naval Postgraduate School.*—It is theoretically shown that there can exist in the positive column a traveling wave of densities and electric field along the axis, superimposed on the average drift current and the well-known uniform ambipolar diffusion in the radial direction. The wavelength of this type of oscillations is given in the lowest approximation by $\lambda=(2\pi R/\mu)[1+a^2(Ee/kT)^2]$ and its propagation velocity is of the order of magnitude of the sound velocity of the neutral gas in the tube; $R$=tube radius, $\mu=2.4$, $a$=electronic Debye-Hückel radius, $E$=electric field, $k$=Boltzmann constant, $T$=electron temperature, and $e$=electronic charge.

**R4. Cyclotron Resonance of Free Electrons in a Nitrogen Afterglow.** R. V. JONES, W. DOBROWOLSKY, W. B. KUNKEL, AND C. D. JEFFRIES, *University of California, Berkeley.*—Nitrogen gas at a few mm pressure containing a trace of oxygen is pumped through a discharge into a $TE_{011}$ mode cavity, which is the sensitive element of a paramagnetic resonance absorption spectrometer operating at 8600 mc/s. We observe simultaneously the paramagnetic resonance of atomic $N$ in the ground state[1] and the cyclotron resonance of free electrons[2] produced by the self-ionization of active nitrogen. This provides a means of comparing the relative abundances of atoms and electrons, which should be useful for afterglow studies. Also the method is quite sensitive to electrons, densities down to $10^9$ electrons/cc being detectable. The resonance line width is directly related to the mean collision time of the electrons in the gas, and varies from a few gauss at low pressures up to about $10^3$ gauss at higher pressures and microwave powers. These results are in reasonable agreement with theory. We have not observed the paramagnetic resonance of atomic $N$ metastable states. This research has been supported in part by the Research Corporation and the U. S. Atomic Energy Commission.

[1] M. A. Heald and R. Beringer, Phys. Rev. **96**, 645 (1954).
[2] J. W. Benson, J. App. Phys. **23**, 757 (1952).

**R5.** (Abstract withdrawn.)

**R6. The Measurement of the Coefficient of Secondary Electron Emission with a Resonant Cavity.** R. K. SMITHER, *Yale University.*—Under certain conditions a secondary electron-resonant discharge process occurs in the electrical field regions of a resonant cavity. If a dc field is added to the rf field in the discharge region a net flow of current is observed which can be related to the coefficient of secondary electron emission ($\delta$). When the proper dc field is applied, the square of the coefficient of secondary emission is given by

$$\delta^2=1+\frac{2I_{d0}}{I_0},$$

where $I_{d0}$ is the current supplied by the dc bias and $I_0$ is the current in the secondary electron resonance discharge. Since the measured quantities appear only in the difference between the square of the coefficient of secondary emission and one, it is possible to obtain good accuracy even when the coefficient is approximately one.

**R7. Measurement of Low-Energy Electron Absorption in Metals and Insulators.** E. J. STERNGLASS AND M. M. WACHTEL, *Westinghouse Research Laboratories.*—A direct method for studying the absorption of slow electrons in solids has been developed. Slow secondary electrons (~0–10 ev) are generated uniformly throughout deposits of 25, 50, and 100 A

±10 percent of Au and 1150, 2600, and 5200 A ±10 percent of KCl supported on a 120 A film of SiO, using 2–20 kev penetrating electrons. The ratio of the low-energy yields $\Delta$ measured at 14–20 kev on the exit side of layers of different thicknesses $d$ gives the diffusion-length $L$ of the slow electrons according to

$$\frac{\Delta_2}{\Delta_1}=\frac{1-\exp(-d_2/L)}{1-\exp(-d_1/L)}.$$

Taking ratios of yields minimizes possible surface effects. Simultaneous measurements of the transmitted primaries serve as check on thickness determinations and absence of pin-holes. For Au, the yield increases little with thickness, the ratio being $\leq 1.23\pm0.04$ for the two thinnest layers. This leads to $L\leq 18$ A, indicating that electrons capable of inelastic collisions can diffuse only a few atomic layers. In sharp contrast, the corresponding ratio for KCl is $1.71\pm0.06$, making $L=2300\pm600$ A and demonstrating long diffusion paths of slow electrons able to make only elastic collisions.

**R8. Surface Recombination of Cadmium Sulfide.** S. H. Liebson and E. J. West, *United States Naval Research Laboratory.*—Increased surface recombination of photoconductive cadmium sulfide has been reported by Bube[1] for crystals in a humid atmosphere. Liebson[2] has observed a decrease in the red luminescence of cadmium sulfide in an atmosphere containing electronegative gases. We have measured this decrease in luminescence as a function of oxygen pressure from about $2\times10^{-6}$ to approximately 500 mm Hg for crystals which were photoconductive and high impedance as well as those which were low impedance at room temperature. The results indicate a linear variation of the logarithm of the luminescence *vs* the pressure. Several interpretations are discussed based on the formation of an electric field at the surface due to electrons on chemisorbed oxygen.

[1] R. H. Bube, J. Chem. Phys. **21**, 1409 (1953).
[2] S. H. Liebson, J. Electrochem. Soc. **101**, 359 (1954).

**R9. Cross Sections for the Characteristic Energy Loss of Electrons.** Lewis B. Leder and L. Marton, *National Bureau of Standards.*—Previous measurements[1] of the characteristic energy losses of electrons in solids have been made primarily using photographic detection. We have now improved our apparatus so that we can measure absolute intensity relationships using a calibrated photomultiplier detector. The detector system consists of a phosphor coated glass window over a 1P21 photomultiplier. The multiplier signal is fed to a logarithmic amplifier the output of which is recorded on a Speedomax. The recorded signal is calibrated with a Faraday cage and quartz fiber electrometer. From these measurements we can determine the ratio of the elastic scattering to the characteristic scattering peak intensities as well as the differential cross sections for these events. The rectangular detector slit defines an acceptance angle of $10^{-3}$ radian in one direction and $10^{-4}$ radian at right angles. Thus the differential cross sections measured are given for a solid angle of $(10^{-3})^2$ or $10^{-6}$ steradian. At a primary energy of 30 kev the ratio elastic/characteristic for 400-A gold is 3.4 and for 100-A carbon is 7.4. The variation of these ratios and of the differential cross sections with thickness and primary energy will be given.

[1] L. Marton and L. B. Leder, Phys. Rev. **94**, 203 (1954) (earlier references are given here).

**R10. Angular Dependence of the Characteristic Energy Loss of Electrons Passing Through Metal Foils.*** R. A. Ferrell, *University of Maryland.*—From the Bohm-Pines[1] electron plasma theory of metals, an electron of energy, $E$, upon passing through a metal foil of thickness $t$, excites a plasma oscillation of quantum energy $\Delta E$ and scatterers into the solid angle $d\Omega$, with probability $td1/\lambda=t/2\pi a_0\cdot\theta_E/\theta_E^3+\theta^2\cdot d\Omega$, where $\theta_E=\Delta E/2E\theta$ = angle of scattering $\leq pc/(2mE)^{\frac{1}{2}}$, $pc$ = cut-off momentum, and $a_0$ = Bohr radius. Although other mechanisms, such as atomic excitation, in general compete with plasma oscillations in producing characteristic energy losses, the angular dependence should identify the mechanism in any given case. For example, recent experimental measurements[2] of the angular distribution of 20-kev electrons scattered by 100 A gold foils show a peaking of the 24-ev loss at small angles ($<10^{-2}$ radian), in qualitative agreement with the expressions for $d1/\lambda$, but not easily interpretible in terms of atomic excitation, (which would give a broader angular dependence). Improvements in $d1/\lambda$ to allow for elastic scattering by the lattice will be discussed.

* Research supported by the Office of Naval Research.
[1] D. Bohm and D. Pines, Phys. Rev. **92**, 609 (1953) and D. Pines, Phys. Rev. **92**, 626 (1953).
[2] Marton, Simpson, McGraw, Mendlowitz, Mendlowitz, and Marton, Bull. Am. Phys. Soc. **30**, No. 1, 29 (1955), abstracts LA2 and LA1.

**R11. Mean Free Path for Discrete Electron Energy Losses in Metallic Foils.** R. D. Birkhoff, A. W. Blackstock,* and R. H. Ritchie, *Oak Ridge National Laboratory.*—The discrete energy losses observed when a beam of electrons passes through a thin foil have been studied as a function of incident energy. Foils of Al, Mg, and Cu ranging in thickness from 14 to 85 $\mu g/cm^2$ have been bombarded with electrons of energies 25 to 115 kev. Losses appear at multiples of 14.9 ev and 10.7 ev, respectively, for Al and Mg whereas only one loss is found in Cu at 22.6 ev. Mean free paths for the losses lie in the range $25\pm10$ $\mu g/cm^2$, $165\pm55$ $\mu g/cm^2$, and $90\pm30$ $\mu g/cm^2$ for the three metals. The magnitudes of the losses agree with the plasma oscillation theory of Pines and Bohm for Al and Mg if the number of free electrons per atom is chosen about equal to the valence. In addition the mean free path as a function of energy for Al agrees closely with the theoretical curve.

* Oak Ridge Institute of Nuclear Studies Fellow from North Carolina State College.

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## Friday Afternoon at 2:00

Caribar Room

(L. I. Schiff presiding)

## *Theoretical Physics III, Mainly Nuclear Theory*

**RA1. On the Imaginary Part of the Potential in the Optical Model of the Nucleus.** A. M. Lane and C. F. Wandel, *M.I.T.* (introduced by V. F. Weisskopf).—The dependence of the imaginary part of the "Weisskopf" potential on the neutron bombarding energy is calculated by an extension of the semiclassical method of Goldberger.[1] The nucleus is described by the statistical model. Using the nucleon-nucleon experimental cross section, and taking the Pauli exclusion principle into account, we calculate an effective total cross section in nuclear matter. The Pauli principle is assumed to forbid colli-

sions which do not bring both particles outside the Fermi momentum sphere in momentum space. Assuming an analytic expression ($1/E$ law) for the nucleon-nucleon cross section, the integrations over the Fermi distribution can be carried out in closed form. Given the effective cross section, a mean-free path and an imaginary potential can be computed. Despite the crude model used, a good fit with experimentally determined imaginary potentials is obtained. In the range from 0 to 100 Mev bombarding energies $|V_{im}|$ increases from 2 to 11 Mev. This, we believe, confirms the importance of the Pauli principle in explaining the long mean free path inside nuclear matter at low energies.[3]

[1] M. L. Goldberger, Phys. Rev. **74**, 1269 (1948).
[2] V. F. Weisskopf, Science **113**, 101 (1951).

**RA2. Nuclear Oscillator Potential.** D. C. PEASLEE, *Purdue University.*—Some consequences are considered of constructing an effective harmonic oscillator well to fit the single-particle interpretation[1] of the photonuclear "giant resonances." Consistency with 0–4-Mev neutron scattering on the optical model with $r_0 \approx 1.2 \times 10^{-13}$ cm implies an effective nucleon mass in the nucleus of order $M^* \sim \frac{1}{2}M$. The depth of the corresponding effective parabolic well approaches 200 Mev. Under these conditions, the Thomas (relativistic) term is sufficient to account for the spin-orbit splitting in the shell model, which then has no direct relation to polarization effects in high-energy scattering. The value $g_L \approx 1$ for protons in nuclei indicates that the velocity-dependent forces responsible for $M^*$ involve only the radial momentum component, for which a plausibility argument can be given.

[1] D. H. Wilkinson, Bull. Am. Phys. Soc. **30** (1), 25 (1955), paper IA4.

**RA3. Collective Modes in Nuclei.** F. COESTER, *State University of Iowa.*—The Hamiltonian of the "unified model" of Bohr[1–3] and Mottelson[2] has been derived from many-particle quantum mechanics. A point transformation in the configuration space of the $N$ nucleons of the core introduces 6 collective coordinates describing the size and shape of the nucleus and $3N-6$ internal coordinates. It is assumed that the wave function $\Psi$ of the nucleus for the ground-state and the low-lying excited states can be approximated by the product $\Psi_0\Phi$ where $\Psi_0$ depends only on the internal coordinates of the core and $\Phi$ depends on the collective coordinates of the core and the coordinates of the external nucleons. $\Psi_0\Phi$ is treated as a trial function in the Schrödinger variational principle. For fixed $\Psi_0$ this yields a Schrödinger equation for $\Phi$. The Hamiltonian in this equation is the Hamiltonian of Bohr and Mottelson plus certain correction terms. $\Psi_0$ influences the values of the constant parameters occurring in this Hamiltonian, but not its structure.

[1] A. Bohr, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **26**, No. 14 (1952).
[2] A. Bohr and B. R. Mottelson, Kg. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953).
[3] A. Bohr, thesis, Copenhagen (1954).

**RA4. The Variational Approach to Collective Nuclear Behaviour.** JAMES J. GRIFFIN, *Princeton University.*—A "temporary potential" is assumed, the shape of which depends upon one or more deformation coordinates. The wave equation is solved for a fixed value of the deformation. The wave function is multiplied by an arbitrary function of deformation and integrated over deformation. The resultant pure $n$-particle wave function is used to evaluate the expectation value of the energy of the system. The integrations over particle coordinates are performed explicitly. The resultant energy is a function of the undetermined deformation weighting function. The condition of minimum energy determines a wave equation (integral equation) for this "collective wave function."[1] The kernels in the collective wave equation have been evaluated in special instances of a single deformation coordinate, and will be discussed. Their form suggests comparison with a simplified problem where the kernel is the product of a quadratic function with a Gauss function. This comparison allows one to estimate a decrease of the order of ~2 Mev in the ground-state energy as a result of allowing a fluctuation in deformation (collective vibration) as compared with the conventional treatment with fixed deformation and fixed potential.

[1] David L. Hill and John A. Wheeler, Phys. Rev. **89**, 1102 (1953).

**RA5. Coupling of $2s_{\frac{1}{2}}$ and $1d_{\frac{1}{2}}$ Orbitals.** P. GOLDHAMMER AND E. FEENBERG, *Washington University.**—Coupling between $2s_{\frac{1}{2}}$ and $1d_{\frac{1}{2}}$ nucleon orbitals through the mediation of surface waves has been investigated in the mass range 29 to 37. A single nucleon description appropriate for $_{14}Si_{15}$ and $_{15}P_{14}$, and a three nucleon description with $T=\frac{1}{2}$ appropriate for $_{14}Si_{17}$ and $_{17}Cl_{20}$ (3 proton holes) have been treated by the intermediate coupling procedure considering only states with 0, 1, and 2 surfons. $(2s_{\frac{1}{2}})^2(1d_{\frac{1}{2}})^1$, $(2s_{\frac{1}{2}})^1$ $(1d_{\frac{1}{2}})^2$, and $(1d_{\frac{1}{2}})^3$ configurations are coupled in the three nucleon systems. $M1$ transition matrix elements between $I=\frac{3}{2}^+$ and $I=\frac{1}{2}^+$ are small, but not "$l$-forbidden" as they are for pure $1d_{\frac{1}{2}} \rightarrow 2s_{\frac{1}{2}}$ transitions. The "$l$-forbidden" $\frac{3}{2}^+ \rightarrow \frac{1}{2}^+$ G.T. matrix element in the decay $_{15}P_{14} \rightarrow {}_{14}Si_{15}$ has the value 0.026 (experimental value 0.040).† The correction to the $\mu_{\frac{1}{2}}$ Schmidt moment in $_{14}Si_{15}$ is about one half the experimental deviation; while the correction to the $\mu_{\frac{1}{2}}$ Schmidt moment for $_{17}Cl_{20}$ is 0.788, compared to 0.552 observed. Quadrupole moments appear too large by a factor of three. Similar calculations for three nucleon systems with $T=\frac{1}{2}$ yield results applicable to $_{15}P_{16}$ and $_{18}A_{19}$.

* Assisted in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Roderick, Lönsjö, and Meyerhof, Phys. Rev. **97**, 97 (1955).

**RA6. Intermediate Coupling in the $1p$ Shell.** DIETER KURATH, *Argonne National Laboratory.*—Since neither the $LS$ or the $jj$ limit of the independent particle model provides a satisfactory picture for nuclei in the region between $He^4$ and $O^{16}$, it is of interest to see whether spin-orbit coupling of intermediate strength can explain the observation. A calculation has been made including all possible configurations within the $1p$ shell using the Argonne electronic digital computer (AVIDAC). The strength of spin-orbit coupling is taken from $O^{15}$, $N^{15}$ where the $1p_{\frac{1}{2}}-1p_{\frac{3}{2}}$ splitting is about 6.3 Mev. The two-body interaction used is the central force mixture of 0.8 Majorana and 0.2 Bartlett with an inverted Gaussian spatial dependence. Energy levels, magnetic moments, and quadrupole moments will be presented.

**RA7. Particle States in a Spheroidal Potential.*** STEVEN A. MOSZKOWSKI, *University of California.*—To study the effect of deviations from sphericity on nuclear energy levels and wave functions, some spheroidal potentials have been considered, especially that of a spheroidal box (axes $D^{-\frac{1}{3}}R_0$, $D^{-\frac{1}{3}}R_0$, $DR_0$). For this case, define $x'=D^{\frac{1}{3}}x$, $y'=D^{\frac{1}{3}}y$, $z'=D^{-\frac{1}{3}}z$. In the primed coordinate system, the difference between this spheroidal box and a spherical one with the same $R_0$, wave functions $\psi_i(\mathbf{r})$ and energies $E_i$ is a change in the *kinetic* energy, for which matrix elements, taken between zero order states $\psi_i(\mathbf{r}')$ are easily computed. The resulting secular equation reads: $(E-E_i')\psi_i(\mathbf{r}')=\Sigma_k H_{ik}\psi_k(\mathbf{r}')$ where $3E_i'=(2D+D^{-2})E_i$. $3H_{ik} \cong -2(D-D^{-2})|P_2(\theta)|_{ik}E_i$, if $i$ and $k$ are in the same major shell and is small otherwise. This method was used to calculate energy levels of a spheroidal box, both without and with an additional spin-orbit term of essentially the form $\hbar\omega \cdot \mathbf{l}$. For more general spheroidal potentials $V(r')$ which increase monotonically with $r'$ and which are reasonably flat for small $r'$, the above results still hold approximately with the following modifications: In $\psi_i(\mathbf{r}')$, $E_i'$ and $H_{ik}$, $D$ is replaced by $D^f$, where $f$ is the ratio of kinetic energy to total energy, measured from the bottom of the well.

* Work partially supported by the Office of Naval Research and the Office of Ordnance Research.

**RA8. Nuclear Forces and the Beta Decay of $C^{14}$.*** WILLIAM M. VISSCHER AND RICHARD A. FERRELL, *University of Maryland.*—The long $C^{14}$ lifetime, apparently in contradiction with beta-decay theory (allowed Gamow-Teller transition), and with the experimentally observed allowed spectrum,[1] can be accounted for by a sufficiently large admixture of tensor force, as has been shown by Talmi and Jancovici.[2] We find that there is a wide range of values of the nuclear force parameters for which the beta-decay matrix element, calculated using harmonic oscillator $p$-state wave functions and Gaussian potentials, is arbitrarily small. Parameters chosen to vary were tensor force strength and range, and spin-orbit strength. The results, fairly insensitive to tensor force range, require that the tensor strength be roughly proportional to the spin-orbit strength. Large or small values for both are permitted. The spin-orbit strength indicated by experiment corresponds to a tensor force strong enough to cause a considerable mixing of $d$-configuration, whose effect on the beta lifetime may be calculated, leading to a corrected relation between the force parameters.

* Supported by the Office of Naval Research.
[1] A. Moljk and S. C. Curran, Phys. Rev. **96**, 395 (1954).
[2] B. Jancovici and I. Talmi, Phys. Rev. **95**, 289 (1954).

**RA9. Interaction Contribution to Nuclear Isomerism.** A. ROTENBERG AND L. SPRUCH, *New York University.*—It has been observed[1] that certain magnetic dipole transitions offer the possibility of distinguishing between the effects of interaction moment operators and of impure wave functions, but at that time[1] only a few estimates of transition lifetimes were available. Many accurate measurements have since been made of the lifetimes of so-called forbidden magnetic dipole transitions and also of a few lifetimes which seem to be forbidden magnetic octupole transitions. Transition probabilities were calculated using the shell model and interaction moment operators. In the dipole case, the operators considered were the three used in a phenomenological analysis of magnetic moment data,[2] only one of which gives a nonvanishing contribution. In the octupole case, the operator was obtained by an extension of a calculation performed by Villars and Weisskopf.[3] The calculations indicate that it is possible to explain most of the data on the Mayer model, which is a desirable feature for those transitions not readily explainable on a Bohr-Mottelson model.

[1] M. Ross, Phys. Rev. **88**, 935 (1952).
[2] A. Russek and L. Spruch, Phys. Rev. **87**, 1111 (1952).
[3] F. Villars and V. F. Weisskopf (unpublished).

**RA10. Theoretical Results on Orbital Capture.** H. BRYSK AND M. E. ROSE, *Oak Ridge National Laboratory.*—A detailed survey of the theory of orbital capture has been carried out. Transition probabilities for the $K$-shell and all three $L$-subshells have been examined for all orders of forbiddenness through second-forbidden, using wave functions corrected for the finite size of the nucleus and the effect of screening, and considering the variation in the wave functions over the nuclear volume (Oak Ridge National Laboratory 1830). Some of the conclusions that can be drawn are: The $L_1/K$ branching ratio agrees with Rose and Jackson's values, and is independent of the order of forbiddenness provided that the neutrino energy is large compared to the difference in binding energy between the two shells. The effect on the $L_1/K$ capture ratio of nonadiabatic electron transitions is unimportant. The $p$-electron contribution to orbital capture becomes dominant for low-energy transitions involving an angular momentum change of two or more. Angular correlations exist among the electromagnetic radiations associated with orbital capture (inner bremsstrahlung photon, atomic x-ray, gamma ray from an excited daughter nucleus) (Oak Ridge National Laboratory 1862). In most cases of interest, however, there is isotropy. In fact, the conditions required for the observation of anisotropy are at present experimentally unattainable.

**RA11. Nuclear Charge Distribution in $Pb^{208}$.*** DAVID L. HILL AND BURTON E. FREEMAN, *Los Alamos Scientific Laboratory,* AND KENNETH W. FORD, *Indiana University.*—The cross section according to the exact Dirac-Darwin-Mott theory for the elastic scattering of fast electrons from various conceivable spherically symmetric nuclear charge distributions has been evaluated accurately and compared with recent Stanford data taken at 83, 153, and 186 Mev with a $Pb^{208}$ target. We find that the data can be fit within the limits set by experimental uncertainties, and that the same charge distribution gives the best fit at each energy. This charge distribution has a radial dependence given by $1-\frac{1}{2}\exp[-n(1-x)]$ for $x\equiv(r/R)\leq 1$ and given by $\frac{1}{2}\exp[-n(x-1)]$ for $x\geq 1$, with $n=10$, and $R=6.7\times10^{-13}$ cm. Appreciable peaking of the charge distribution either at the center or surface of the nucleus evidently does not exist. The value of $R$ here found agrees within 1 or 2 percent with the value earlier determined[1] by an analysis of mu-mesonic x-ray data. Radiative corrections omitted in this analysis of electron scattering probably are unimportant in determining the charge distribution, and corrections for inelastic scattering are negligible in $Pb^{208}$. The analysis indicates a high degree of determination for the nuclear charge distribution as the experimental data becomes more complete.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] D. L. Hill and K. W. Ford, Phys. Rev. **94**, 1617 (1954).

**RA12. Validity of Deformation-Potential Theory in $N$-Type Ge.** R. ROSENBERG* AND M. LAX, *Syracuse University.*—The Bardeen-Shockley deformation-potential theory, based on a model of spherical energy surfaces about the origin of the Brillouin zone, predicts electron scattering only by the long-wavelength longitudinal acoustic modes of lattice vibration. In $N$-type Ge, however, the multi-ellipsoid model of energy surfaces applies, and the electron is scattered by all three acoustic branches and by the three optical branches of the vibrational spectrum. Moreover, the electron can make "intra-ellipsoid" and "inter-ellipsoid" transitions. The present analysis of electron-lattice scattering employs an interaction Hamiltonian which is a linear form in the displacements of the lattice particles from their equilibrium positions. The properties of the coefficients of the particle displacements are determined from the symmetry group of the crystal. Seven matrix elements of the linear form (one of which is $E_1$, the constant appearing in deformation-potential theory) are required to specify electron-lattice scattering processes in $N$-type Ge, on the assumption that the energy minima occur near the boundary of the Brillouin zone. Symmetry arguments are used to reduce this number. $N$-type Si is also discussed.

* This work was supported in part by the Office of Naval Research, and constitutes part of a Ph.D. thesis in preparation at Syracuse University.

**RA13. Dynamics of the Klein Particle.** DAVID FINKELSTEIN, *Stevens Institute of Technology and New York University.*—A notion of a covariant rigid localized system has been defined.[1] It has been shown that all such can be obtained by imposing covariant constraints upon a particular covariant system of six degrees of freedom which is due to F. Klein.[2] The previous discussion was limited to the kinematics of these systems. Now the classical and quantum dynamics will be treated. Two choices of action integral will be presented. The first action is chosen with an eye to obtaining a Dirac-like particle as one of the spin states of the Klein particle, and is linear in the velocity. The second action is mathematically more natural, being merely the arc length on the configuration space, but this leads to a nonlocal wave equation for the quantized particle. For the present purposes, the canonical quantization procedure is adequate.

[1] D. Finkelstein, Bull. Am. Phys. Soc. **30**, No. 1, 36 (1955), abstract OA5.
[2] F. Klein, *The Mathematical Theory of the Top* (Princeton University Press, Princeton, New Jersey, 1896).

**RA14. Elementary Particle Models.** T. F. MORRIS, *McGill University.*—Theories of elementary particles are investigated, which are characterized by the existence of an incompatibility between mass and space-time position measurements. Several mass operators with positive definite spectra have been obtained. In momentum space the wave function is easily decomposed into components which transform according to various representations of the inhomogeneous Lorentz group. Hence the quantization of the theory is straightforward. Although the introduction of subsidiary variables, similar to those used by Yukawa, is necessary, the interpretation remains within the scope of local fields. Several types of interaction are considered.

**RA15. Certain Matters Pertaining to the Internal Structure of Nucleons.*** W. F. G. SWANN, *Bartol Research Foundation.*—In 1948, the writer[1] criticized the statement that the mass-energy relation for rest mass is contained in the restricted theory of relativity. It was shown that the statement could be validated by regarding each nucleon as composed of a very large number of subparticles of negligible rest mass, moving with velocities very nearly equal to the velocity of light. In the present paper, the foregoing idea is crystalized into more concrete form by assuming that the motions of the subparticles are axially symmetrical within a nucleon. The discussion then pertains to the elements involved and the mathematical possibilities open in providing for the spin characteristics of the various nucleons. Finally, insofar as the macroscopic concept of a potential energy $V$ for the forces between nucleons turns out to be $\Sigma_i M_{0i}c^2$, where $M_{0i}$ is the rest mass of the $i$th nucleon in the configuration to which $V$ applies, a discussion is made of the possibilities as regards ultimate forces, between the subparticles, necessary to provide for the correlation between $V$ and $\Sigma_i M_{0i}c^2$ consistent with experience.

* Assisted in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Phys. Rev. **74**, 202 (1948).

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FRIDAY EVENING AT 7:00

Sheraton Park, Continental Room

(R. T. BIRGE presiding)

***Banquet of the American Physical Society***

**After-dinner speakers:** R. W. G. Wyckoff and John von Neuman

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SATURDAY MORNING AT 9:30

Exhibit Hall I

(S. W. BARNES presiding)

***Mesons, I***

**S1. Electromagnetic Production of μ Mesons.*** G. E. MASEK, A. J. LAZARUS, AND W. K. H. PANOFSKY, *Stanford University.*—We have made measurements on the yield of negative $\mu$ mesons emitted from a $\frac{1}{2}$-radiation-length copper target at 10° and 30° to an incident 550-Mev electron beam. The angle of emission and the momentum of the mesons are selected by a magnet system. Various absorbers give a maximum rejection of $\mu^-$ from $\pi^-$ decay in flight and the $\mu^-$'s from electromagnetic production are stopped above a triple-coincidence counter telescope. The decay electrons are counted with the telescope through delayed electronic gates. If it is assumed, and it has been verified, that the $\pi$ production is substantially isotropic, then any large difference from isotropy between 10° and 30° is attributed to $\mu$-pair production. The purely electromagnetic (including nuclear-size effect) cross sections for a single member of the $\mu$ pair have been calculated at 10° and 30° by Rawitscher[1] to be $d^2\sigma/d\Omega dT_\mu = 2.1\times10^{-23}$ cm²/(sterad ×Mev×equivalent quanta) at 10°, and 550-Mev bremsstrahlung and 225-Mev meson kinetic energy. (For 30° the cross section is 1/50 of this.) Our results show that the experimental cross section is not larger than and might be compatible with this number.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. Rawitscher, Bull. Am. Phys. Soc. **29**, No. 8, 24 (1954), abstract O5.

**S2. μ−e Decay Spectrum.*** R. H. HELM, K. M. CROWE, AND G. W. TAUTFEST, *Stanford University.*—The preliminary analysis of an experiment on the $\mu$–$e$ decay spectrum has yielded data which seem to be relatively simple to interpret. Delayed positrons from the $\pi^+\to\mu^+\to\beta^+$ decay in a Li or C target in the 500-Mev bremsstrahlung beam are magnetically analyzed by a 180° point-focusing spectrometer and counted by a thin-crystal telescope. The maximum positron energy occurs at a field of 4500 gauss. The net resolution is observed to be 4–10 percent full width at half-maximum, depending on the size of targets and detectors, and arising mainly from energy loss of positrons leaving the target. The spectrum obtained is being analyzed in terms of the $\rho$ parameter introduced by Michel.[1] The best value of $\rho$ is $0.55\pm0.10$. The stated error is divided among: our statistics, the resolution (which is currently being recomputed), and systematic uncertainties (background, etc.). This value is in agreement with a number of other measurements of roughly the same accuracy, but is inconsistent with the extremely accurate values reported by Sagane *et al.*[2]

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] L. Michel, Proc. Phys. Soc. (London) **A63**, 514 (1950).
[2] Sagane, Dudziak, and Vedder, Phys. Rev. **95**, 863 (1954).

**S3. Mesonic Decay of an Ejected Triton.** HERMAN YAGODA, *National Institutes of Health.*—A heavy fragment is ejected from a star of type $21+5p$ which decays at rest into three charged particles. Gap counts indicate that the excited fragment is singly charged and heavier than a proton. The mass of the particle, as estimated by constant sagitta scattering along its range of 1330 microns, is $2.93\pm1.36$ proton masses. All three secondary particles terminate their range, and one of them can be identified as a negative pi meson of $26.6\pm0.9$ Mev kinetic energy. Two short recoil tracks, if assumed to be protons, have kinetic energies of $1.43\pm0.04$ and $2.31\pm0.15$ Mev, respectively. Momenta balances applied to several decay schemes suggest that the event probably represents $H^{3*}\rightarrow H^1+H^1+\pi^0+\pi^-+Q=31.5\pm1$ Mev. The binding energy of the excited triton, $5.4\pm1$ Mev, is found to be less than that of the normal triton (8.48 Mev). The time of flight of the particle is $4.2\times10^{-11}$ sec. The event was recorded in a G-5 emulsion, 1500 microns thick, exposed to cosmic radiation in the stratosphere. This example of the mesonic-decay of a "*V*-triton" is in close agreement with theory.[1]

[1] W. Cheston and H. Primakoff, Phys. Rev. **92**, 1541 (1953).

**S4. Cross Section for $p+p\rightarrow\pi^++p+n$.*** D. STORK AND S. WHETSTONE, *University of California, Berkeley.*—The 0° cross section for $p+p\rightarrow\pi^++p+n$ (1) has been measured as a function of pion energy for protons of energy 338 Mev. The pions were detected in flight by means of scintillation-counter, pulse-height techniques. A combination of quadrupole and wedge magnetic focusing provided a pion energy resolution of $\pm0.7$ Mev. With a spread of proton beam energy of $\pm1.2$ Mev the pion energy continuum of reaction (1) was separated from the peak caused by the reaction $p+p\rightarrow\pi^++d$ (2). The ratio of the total cross sections $(d\sigma/d\Omega)$ for reactions (1) and (2) is in good agreement with the Watson-Brueckner phenomenological theory.[1] However, the shape of the energy spectrum of reaction (1) shows a considerable deviation from that given by the phenomenological theory for *P*-wave pions and a final two-nucleon *S*-state.[2]

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] K. M. Watson and K. A. Brueckner, Phys. Rev. **83**, 1 (1951).
[2] A. H. Rosenfeld, Phys. Rev. **96**, 139 (1954).

**S5. $\pi^+/\pi^-$ Ratios Produced by 340-Mev Protons at 0°.** J. E. CAROTHERS AND C. G. ANDRE,* *University of California.*—The $\pi^+/\pi^-$ ratio has been measured for several elements at 0° to the 340-Mev proton beam of the Berkeley cyclotron. The detection scheme and the ratios obtained for deuterium have been described in a previous letter.[1] The most important feature of the detection scheme is that it allows a direct comparison of the positive and negative yield. A magnetic field separates the mesons from the proton beam and separates the different charges. When the field is reversed, particles of the opposite sign are counted by the detectors. The ratios obtained

TABLE I.

| Energy (Mev) | $D(\pi^+/\pi^-)$ | $He(\pi^+/\pi^-)$ | $Be(\pi^+/\pi^-)$ | $C(\pi^+/\pi^-)$ | $Pb(\pi^+/\pi^-)$ |
|---|---|---|---|---|---|
| 30 | $5.8\pm2.5$ | $3.4\pm2.2$ | $4.3\pm1.2$ | $4.5\pm1.6$ | $0.83\pm0.6$ |
| 60 | $22.1\pm3.5$ | $10.8\pm2.1$ | $9.2\pm1.2$ | $10.9\pm1.6$ | $1.7\pm1.0$ |
| 120 | | $35.1\pm18.3$ | $12.7\pm1.8$ | $14.5\pm1.9$ | $6.7\pm3.2$ |

* Now at Calvin College, Grand Rapids, Michigan.
[1] J. Carothers and C. G. Andre, Phys. Rev. **88**, 1426 (1952).

are listed in Table I. The energies listed are those accepted by the magnetic channel. The large errors are the result of the very low $\pi^-$ production, which lead to low counting rates.

**S6. Pion Production by Neutrons on Helium.*** PETER H. MOULTHROP, *University of California, Berkeley.*—A helium-filled 36-atmosphere diffusion cloud chamber in a pulsed 21 000-gauss magnetic field was operated in the 300-Mev neutron beam of the 184-inch cyclotron. Two hundred and ninety five negative pions were found. The dominant reactions were $\alpha(n,p\pi^-)He^3$ and $\alpha(n,d\pi^-)He^3$, each contributing about 30 percent to the total cross section for negative pion production. The reaction $\alpha(n,p\pi^-)\alpha$ contributed less than 10 percent. Partial cross sections, energy, and angular distribution data will be presented.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**S7. Pion Production from Hydrogen by 600-Mev Electrons.*** W. K. H. PANOFSKY AND G. B. YODH, *Stanford University.*—The ratio of bremsstrahlung-produced to electron-produced pions from hydrogen has been measured using a liquid-hydrogen target. Pions of 55 and 75 Mev at 75° to a 600-Mev electron beam were observed. The data have been reduced to "effective radiation lengths" for electron-pion production, $X_e$, which is the thickness of a fictitious radiator that would double the yield with electrons directly. The results are $X_e=0.0256\pm0.0030$ and $X_e=0.0199\pm0.0022$ at pion energies of 55 and 75 Mev, respectively. The results are consistent with either electric-dipole or magnetic-dipole absorption.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.

**S8. $\pi^+$ Photomeson Production at 143°.** R. STEPHEN WHITE, MARK J. JAKOBSON, AND GORDON W. REPP, *University of California, Berkeley.*—Liquid hydrogen and deuterium targets have been bombarded by the bremsstrahlung from the Berkeley synchrotron; $\pi^+$ mesons were observed at 143° to the beam. The detection of $\pi^+$ mesons was by means of a coincidence between the stopping $\pi^+$ meson and the positron from the $\mu^+$ meson decay in a single plastic crystal. For thin absorbers (low-energy mesons) pulse-height analysis was done on the $\pi^+$-meson pulse. Absolute cross sections were obtained with the help of emulsions exposed to $\pi^\pm$ mesons from deuterium. The excitation function at 143° for $\pi^+$-meson production from hydrogen and deuterium-hydrogen ratios will be given. The data will be compared to those of other laboratories and with theoretical predictions.[1] This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Geoffrey F. Chew, Phys. Rev. **95**, 1669 (1954).

**S9. Neutral Photomesons from Hydrogen.*** F. E. MILLS† AND L. J. KOESTER, JR., *University of Illinois.*—Total cross sections for the photoproduction of $\pi^0$ mesons in hydrogen have been measured from threshold to 240 Mev. One of the $\pi^0$-decay $\gamma$ rays from a liquid-hydrogen target was detected in a scintillation-counter telescope. The detection efficiency of this telescope was calculated by a Monte Carlo method. Counting rates at laboratory angles of 84° and 130° were measured as the betatron energy was varied in 10 Mev steps. Analysis of these data by the photon difference method yields the cross sections for production of decay $\gamma$ rays. The kinematics of the decay process establish relations between these $\gamma$-ray cross sections and the $\pi^0$ cross sections. In this energy range, the 84° $\gamma$-ray cross section proves to be a measure of the $\pi^0$ total cross section. An $S-P$ interference term is indicated by the comparison between the 84° and 130° $\gamma$-ray cross sections. These results will be compared with other experiments and with theory.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Cornell University, Ithaca, New York.

**S10. Neutral Photomesons from Hydrogen.*** L. J. KOESTER, JR., *University of Illinois.*—Differential cross sections for the reaction $h\nu+p\rightarrow\pi^0+p$ have been measured for incident photon energies between 180 and 215 Mev and around 280 Mev. The recoil protons from a liquid-hydrogen target were detected in nuclear emulsions. The c.m.s. angle of the $\pi^0$ was 135° at the lower energies and 110° at 280 Mev. By comparison with

measured total cross sections (preceding abstract) the 135° cross sections indicate a backward asymmetry in the angular distribution which can be explained as interference between *S*- and *P*-waves. The magnitude of the interference term agrees with results of Watson's analysis[1] and of the Chew-Low theory.[2]

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] K. M. Watson, Phys. Rev. **95**, 228 (1954).
[2] G. F. Chew and F. E. Low (private communication).

**S11. Neutral Meson Photoproduction at Forward Meson Angles.*** DALE R. CORSON, *Cornell University*, AND WILLIAM S. MCDONALD AND VINCENT Z. PETERSON, *California Institute of Technology.*—The recoil protons from cold, high-pressure hydrogen gas exposed to the 500-Mev bremsstrahlung of the CalTech synchrotron have been detected in C-2 600 micron emulsions placed within the target chamber. The minimum detectable proton energy is 5 Mev. Pairs of emulsions on opposite sides of the beam were used to minimize errors in beam centering. Range and angle with respect to the beam are measured, the angle being a sensitive measure of the photon energy. Most background tracks may be eliminated by measurement of dip angle. The net background correction, estimated from protons beyond the maximum recoil angle (71°), is 5 percent. Preliminary measurements yield the following cross sections (center of mass) for the reaction $\gamma+P\rightarrow P+\pi^0$:

| Photon energy | $\theta_\pi$ (cm) | $(d\sigma/d\Omega)$ ($\mu$b/sterad) |
|---|---|---|
| 260–340 Mev | 45°–60° | 14.6±2.3 |
| 260–340 Mev | 26°–45° | 9.5±2.0 |
| 340–420 Mev | 26°–45° | 9.2±2.1 |
| 420–500 Mev | 26°–37° | 3.8±2.0 |

An extrapolation of the data of Oakley and Walker[1] at larger meson angles, using their angular distribution coefficients, is consistent with the present data.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] D. Oakley and R. Walker, Phys. Rev. (to be published).

**S12. A Search for the Photoproduction of Meson Pairs in Hydrogen.*** M. SANDS, M. BLOCH, J. G. TEASDALE, AND R. L. WALKER, *California Institute of Technology.*—An attempt has been made to detect negative mesons from the interaction of photons with hydrogen. The existence of negative mesons would imply meson pair production. Mesons produced in a high-pressure hydrogen target by the 500-Mev bremsstrahlung of the CalTech synchrotron were detected by the magnet spectrometer used for other measurements.[1] Accidental coincidences and the electron background were reduced by adding a third counter to the detection apparatus and requiring 3-fold coincidences. Measurements at 73° with respect to the photon beam and using a meson energy window about 10-Mev wide at 47 Mev gave a negative meson intensity for hydrogen $(1.5\pm0.3)\times10^{-2}$ of the intensity of positive mesons of the same energy. Most of the negative mesons were absent in measurements repeated with a 375-Mev bremsstrahlung beam. Lacking further measurements, this number must be considered an *upper bound* for the negative meson intensity. Measurements made at laboratory angles of 30° and 104° will also be reported.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Walker, Teasdale, and Peterson, Phys. Rev. **92**, 1090 (1953).

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## SATURDAY MORNING AT 9:30

## Main Ballroom

## (A. M. WEINBERG presiding)

### *Apparatus of Nuclear Physics, I*

**T1. Four-Pole Permanent-Magnet Rings for Focusing Beams of Charged Particles.*** J. P. BLEWETT, N. C. CHRISTOFILOS, AND A. M. VASH, *Brookhaven National Laboratory.*—The transverse-gradient magnetic-field pattern necessary for alternating gradient focusing of beams of charged particles can be set up inside a cylinder of permanent magnet material by using suitable procedures for magnetization. Gradients of about 800 gauss per cm have been achieved with good linearity in cylinders having an inside diameter of one inch. The present work is aimed at a focusing system for a proton linear accelerator. An approximate analysis of the field pattern to be expected in a cylinder having given magnetic properties indicates that higher gradients should be attained when the four-pole magnetizing system is inside rather than outside the cylinder. It indicates, moreover, that the attainable field gradients using materials of the Ferroxdur, Indox, or Ferrimag class should be materially higher than those reached with Alnico V or Cunico. Both of these predictions have been verified by experiment. The fields are examined by rotating the cylinder about its axis and observing the output of a fixed search-coil. Harmonic analysis of the search coil output permits a study of the various nonlinear terms and an evaluation of the displacements of the magnetic axis from the geometrical axis of the cylinder.

* Work carried out under contract with U. S. Atomic Energy Commission.

**T2. Nonlinearities in the Alternate-Gradient Synchrotron.*** E. D. COURANT, *Brookhaven National Laboratory.*—The equations of motion in an alternating-gradient accelerator necessarily contain nonlinear terms. One may hope that these will ameliorate the effect of the resonance instabilities predicted by the linear theory[1]; one may also fear that the nonlinearities will introduce further instabilities. Numerical computations have been performed on the UNIVAC for a variety of nonlinear problems. It is found that stable equilibrium orbits generally exist, whether or not the corresponding linear problems are stable. If the parameters of the problem are slowly varied during the course of the computation these equilibrium orbits move. The particles generally follow the equilibrium orbits, but under certain conditions they jump from the region of influence of one equilibrium orbit to another; if the nonlinearity is too strong the motion may even become completely unstable. These jumps can be correlated with the resonances of the linear theory. It appears doubtful whether nonlinearities can permit the machine designer to ignore any of the resonances; on the other hand, moderate nonlinearities do not appear to give rise to any deleterious effects not predicted by the linear theory.

* Work carried out under contract with U. S. Atomic Energy Commission.
[1] E. D. Courant, Phys. Rev. **91**, 456A (1953).

**T3. Design Studies for Alternating-Gradient Magnets. Part I: Field Distributions Computed by the Relaxation Method.*** M. HILDRED BLEWETT, *Brookhaven National Laboratory.*—The magnet for an alternating-gradient proton synchrotron must produce a field with a uniform gradient over an aperture

determined by the possible excursions of the particles and should use as little steel as possible. At the same time, saturation effects should appear at as high fields as possible. As a guide in the design of the Brookhaven 25-Bev proton synchrotron, a number of relaxation studies have been made of the field patterns around and in the steel, and in the exciting coils, for a variety of possible magnet configurations. The computed field patterns have indicated several possible modifications in magnet and coil geometry to improve magnet efficiency. In making relaxation computations, with the rather complex boundary conditions necessary for a high-gradient magnet, the ordinary methods involving computation of a vector potential have been found to yield insufficient accuracy in the derived field gradient. A modified potential function has been developed which reduces the computational labor and from which gradients can be computed to better than 1 percent accuracy for magnet-pole contours of arbitrary shape. Conclusions from these studies are being tested on model magnets.

* Work carried out under contract with U. S. Atomic Energy Commission.

**T4. Design Studies for Alternating-Gradient Magnets. Part II: Model Measurements.*** GLEN R. LAMBERTSON,† C. LASKY, AND ROBERT H. PHILLIPS, *Brookhaven National Laboratory.*—Measurements have been made of the dc fields of alternating-gradient synchrotron magnet models of *C*-type configuration with an $n$ of approximately 325. The models measured have a ratio of gap width to mid-gap height equal to 3.5. Gradient measurements using preliminary pole-face contours show a gradient uniform within 2 percent over approximately one half the width of the pole tip. Below 8000 gauss, saturation effects do not appreciably reduce this region. The region narrows rapidly as saturation increases, and above 10 000 gauss attaining the required aperture constitutes a problem. Results of modifying the pole-face contours to extend the usable aperture to higher flux densities will be reported. The measurements are encouraging with respect to the feasibility of accomplishing the alternation of the gradient by reversal of the pole tips on the yoke.

* Work carried out under contract with U. S. Atomic Energy Commission.
† On leave from the Radiation Laboratory, University of California, Berkeley, California.

**T5. Precision Vibrating-Coil Magnetic-Gradient Recorder.*** MARTIN GRAHAM, *Brookhaven National Laboratory.*—The accurate measurement of a magnetic-field gradient is required in the testing of magnets for accelerators under development at Brookhaven National Laboratory. An instrument has been built which vibrates a search coil in the magnetic field, and vibrates a reference coil on the same shaft in a reference magnet. The voltages induced in the two coils are compared in a modified bridge circuit whose null is set by a self-balancing arrangement which also runs a recorder pen. The entire device produces graphs of normalized gradient *versus* radial position in the magnet gap. The ranges of $\partial B/\partial r$ are 0 to 1 gauss/centimeter, and 9 to 10 gauss/centimeter (suppressed zero). Multiplication factors up to $10^3$ are available by use of an attenuator in the search-coil circuit. The performance is limited by thermal noise in the search coil to about $\frac{1}{4}$ percent at the response speeds used.

* Work carried out under contract with U. S. Atomic Energy Commission.

**T6. Scattering of Electrons in a Strong Focusing Synchrotron.*** MICHAEL J. MORAVCSIK AND J. MICHAEL SELLEN, JR., *Cornell University.*—Calculations of the scattering loss are carried out for the 1-Bev Cornell "mesotron" under construction. "Elastic" scattering by nuclei and "inelastic" scattering by atomic electrons are considered. Screening effects are accurately taken into account (by using the Hartree wave function for the smallest scattering angles) because the very small angles relevant in the problem correspond to large impact parameters. Because of these small angles the contribution of the inelastic scattering is just as important as that of the elastic process. It is shown that the total cross section in the highly relativistic limit as given by the Born approximation is independent of energy for any physical central potential where large angle scattering is unimportant. In applying the scattering formula to the synchrotron representative points are selected in the field lattice and the results are averaged over these points. Vertical and radial scattering are treated separately and the cross section for each of these is taken to be half of the whole cross section. The radial case will be complicated by the synchrotron oscillations. Two different injection conditions are considered and it is found that they give roughly the same results because of the damping of oscillations as the energy increases.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**T7. A Method for the Prompt Destruction of the Electron Beam in a Conventional Synchrotron.*** C. L. HAMMER AND A. J. BUREAU, *Iowa State College.*—By passing current through coils wrapped around a section of the donut of a synchrotron it is possible to change the fall off index of a part of the guide field while leaving the remaining guide field unaltered. This technique is used on the Iowa State College 70-Mev synchrotron and complete beam destruction is found experimentally to occur in approximately 0.08 microsecond. The buildup of the radial oscillation is analyzed and it is estimated that complete destruction of the beam is accomplished in approximately 10 revolutions or 0.06 microsecond. The analysis also shows that this technique can be a valuable aid in the extraction of an electron beam from a synchrotron or betatron.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

**T8. Betatron Oscillations in a Fixed-Field Alternate-Gradient Accelerator with Spirally-Ridged Poles.** L. JACKSON LASLETT, *Iowa State College* and Midwestern Universities Research Association.*†—An analysis has been made of the particle trajectories to be expected in a spirally-ridged fixed-field accelerator similar to that described previously by Kerst, *et al.*[1] The field in the median plane is taken to be of the form,

$$H = -H_0(r/r_0)^k[1 + f\sin(w^{-1}\ln(r/r_0) - N\theta],$$

with the result that the basic character of the oscillations remains unaffected by the gradual increase of mean radius during the acceleration cycle. The periodic solution of the equations of motion suggests an equilibrium orbit which is appreciably scalloped. Stability conditions and other features of the betatron motion about this orbit are significantly affected by this scalloped character of the reference orbit. Approximate formulas and numerical examples are presented to illustrate these points.

* Institute for Atomic Research and Ames Laboratory of the U. S. Atomic Energy Commission.
† Assisted by the National Science Foundation.
[1] Kerst, Terwilliger, Symon, and Jones, Bull. Am. Phys. Soc. **30**, No. 1, 14 (1955), abstract D5.

**T9. Synchro-Microtron Requiring No Static Magnetic Guide Field.** H. F. KAISER, *Naval Research Laboratory.*—A previous paper[1] proposed an electron accelerator in which a magnetic field rising stepwise in time is superposed locally on a given static field microtron orbit. Subsequent finite and stepwise electron energy increases are then matched by step increases in magnetic guide field, allowing the particle to reach at constant orbit radius any energy attainable with the superposed field. The theory is now extended to the case where the usual static magnetic field is absent and the particle energy and field increase stepwise from the outset. In previous theory

the step operation began with particle velocity nearly $c$ making the difference in particle and field wave speeds $[\beta_p c - 1/(LC)^{\frac{1}{2}}]$, small and nearly constant. Now the major problem is adjustment of field wave speed to the large charges in $\beta_p$ occurring in the initial turns. Phase conditions resulting from various choices of fixed-field wave velocity are studied and also some schemes for keeping wave and particle speed equal by automatic electronic variation of the field line parameters $(L,C)$ such as gas discharge or ferrite line loading techniques.

[1] H. F. Kaiser, Bull. Am. Phys. Soc. **29**, No. 7, 18 (1954), abstract I8.

**T10. Cyclotron Energy Measurement by Time-of-Flight.*** S. D. Bloom, C. O. Muehlhause, and H. E. Wegner, *Brookhaven National Laboratory.*—In the course of developing time-of-flight techniques for the study of neutrons generated by a cyclotron, the energy and time dispersion of the machine were determined. An unfocused proton beam traveled along an evacuated tube striking a gamma producing target whose position along the flight path could be varied. The gamma rays could be detected with any of the fast organic phosphors or NaI(Tl) in conjunction with either an RCA type 1P21 or 5819 photomultiplier tube. A fast delayed coincidence between the cyclotron radio-frequency (18.56 Mc) and the detector pulse was required, as well as a slow coincidence between the fast coincidence output and a slow channel discriminator pulse. At a fixed time delay in the rf leg of the fast coincidence circuit the spatial distribution of the proton was determined for two positions. These positions were separated in flight time by one rf period (54 mμsec). The following operating parameters were measured: exit orbit circumference, 114±1 cm; proton energy, 2.31±0.02 Mev; time dispersion, 2.5 mμsec. Since no change in time dispersion was observed for the two proton positions and since different spatial sections of the beam were the same energy, it was concluded that the beam is monochromatic to ~1 percent.

* Work done under auspices of the U. S. Atomic Energy Commission.

**T11. An 8-Mev Variable Energy Cyclotron.** H. W. Fulbright, D. A. Bromley, and J. A. Bruner, *University of Rochester.*—Details of the construction and successful operation of the new 27-in. variable energy cyclotron and beam-handling system at the University of Rochester will be described. A proton beam of energy easily and quickly adjustable to any energy from 1.5 to 8 Mev having a narrow energy spread and a current (after analysis) of several tenths of a microampere is produced. Deuterons of 4.5 Mev and alpha particles of 9 Mev have also been generated. The cyclotron employs a single dee and a variable-frequency oscillator.

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## Saturday Morning at 9:30

## Burgundy Room

## (A. J. Allen presiding)

### *Transmutation and Nuclear Energy Levels, III*

**TA1. Gamma Rays from Protons on $P^{31}$.*** J. W. Olness and H. W. Lewis, *Duke University.*—Gamma rays from $P^{31}$ bombarded by protons of 1.4 to 3.36 Mev have been studied with a scintillator. Targets, of thickness less than 10 kev at 2 Mev, were prepared by evaporation of zinc phosphide on thick tantalum. Above 2.30 Mev, twenty-one resonances were observed for the production of a 1.26-Mev gamma ray, attributed to the reaction $P^{31}(pp')P^{31}$. Rather large inconsistencies occur in previously reported energies for the low-lying states of $P^{31}$; we believe that our value for this state is correct to ±15 kev. No evidence for other low-lying states was observed. The gamma spectrum above $E_p = 2.47$ Mev showed the presence of a 1.8 Mev gamma ray, attributed to $P^{31}(p,\alpha\gamma)Si^{28}$, with a resonance structure similar to that of the 1.26 Mev gamma ray. We have also measured the yield of gamma rays greater than 3 Mev in energy, corresponding to capture radiation. All resonances above $E_p = 2.1$ Mev correspond to previously unreported levels in $S^{32}$. Further work with thinner targets and observation of charged particles is planned.

* This work was supported by the U. S. Atomic Energy Commission.

**TA2. The Reaction $P^{31}(p,\alpha)Si^{28}$.** R. L. Clarke, E. Almqvist, and E. B. Paul, *Chalk River Laboratories.*—Zinc phosphide targets have been bombarded by protons of 1.0 to 2.5 Mev energy. Alpha particles leading to the ground state of $Si^{28}$ were observed by means of a double-focusing magnetic spectrometer mounted to detect particles at 90° to the beam. Sixteen well separated resonances were observed. Of these, only two show a measureable γ-ray yield, although many resonances in the $P^{31}(p,\gamma)S^{32}$ reaction have been observed in this region.[1] These two resonances are at 1.90 and 2.03 Mev. The widths and differential cross sections at 90° are listed below for the resonances more than 4 kev wide:

| $E_R$(Mev) | Γ(kev) | $d\sigma/d\Omega(90°)$ (barns/sterad) |
|---|---|---|
| 1.52 | 9.0 | 0.022 |
| 1.64 | ~5 | 0.025 |
| 1.90 | 27 | 0.043 |
| 2.03 | 18 | 0.037 |

The lowest resonance observed in this work is at 1.03 Mev, and overlaps the work of Freeman and Seed.[2]

[1] Gove, Paul, Litherland, and Bartholomew, Phys. Rev. **95**, 650(A) (1954).
[2] J. M. Freeman and J. Seed, Proc. Phys. Soc. (London) **A64**, 313(L) (1951).

**TA3. Neutrons from the Proton Bombardment of $S^{32}$ and $S^{34}$.*** F. Ajzenberg and A. Rubin, *Boston University,* and J. G. Likely, *Princeton University.*—An isotopic sulfur target, 50 kev thick, and an enriched CdS target, 100 kev thick, have been bombarded by 17.5-Mev protons from the Princeton cyclotron. The sulfur target was prepared by the method of Nielsen and Weinstein[1] while the enriched[2] CdS was painted on a polystyrene foil. Preliminary measurements of proton recoil tracks in Ilford C-2 emulsions at 30 and 150 degrees (1500 tracks) indicate four neutron groups corresponding to states in $Cl^{33}$ and five neutron groups corresponding to states in $Cl^{34}$. An attempt will be made to correlate the results of these neutron spectra measurements with the picture of the $Cl^{34}-S^{34}$ decay derived from β-decay measurements.[3]

* This work was supported in part by the U. S. Air Force, through the Office of Scientific Research, and in part by the U. S. Atomic Energy Commission.
[1] E. Nielsen and A. Weinstein, Rev. Sci. Instr. **24**, 1146 (1953).
[2] The CdS, on loan from the Stable Isotopes Division of the U. S. Atomic Energy Commission, was enriched to 14.92 percent $S^{34}$.
[3] P. M. Endt and J. C. Kluyver, Revs. Modern Phys. **26**, 95 (1954).

**TA4. Protons from the Alpha Bombardment of $A^{36}$ and $A^{40}$.*** ROBERT B. SCHWARTZ, JAMES W. CORBETT,† AND WILLIAM W. WATSON, *Yale University.*—Gas targets 150 kev thick of natural argon (99.6 percent $A^{40}$; 0.34 percent $A^{36}$) and of argon enriched in $A^{36}$ (97.4 percent $A^{36}$; 2.5 percent $A^{40}$) have been bombarded with 7.4-Mev alphas from the Yale cyclotron. Protons at 90° to the incident beam have been studied by means of 50-$\mu$ Ilford C-2 emulsions, placed 19 cm from the target. The ground-state $Q$-value for the $A^{36}(\alpha,p)K^{39}$ reaction is $-1.29$ Mev, with excited states at 2.60 and 2.81 Mev. The ground state $Q$ for $A^{40}(\alpha,p)K^{43}$ is $-3.55$ Mev, with excited states at 0.44 and 1.01 Mev. The ground-state $Q$-values are in good agreement with the $Q$'s computed from mass spectrometer and beta-decay data.[1] The rather high energy of the first excited state in $K^{39}$ follows the trend of the first excited states in the other 20-neutron nuclei whose $d_{\frac{3}{2}}$ proton shell is being filled. The cross section for the $A^{40}(\alpha,p)K^{43}$ reaction is quite low—only 4 percent of the cross section for the $A^{36}$ reaction.

* Supported in part by the U. S. Atomic Energy Commission.
† General Electric Coffin Fellow.
[1] R. W. King, Revs. Modern Phys. **26**, 327 (1954); Duckworth, Hogg, and Pennington, Revs. Modern Phys. **26**, 463 (1954).

**TA5. Angular Distribution of Proton Groups from $Ca^{42}(d,p)Ca^{43}$ Reaction.*** C. K. BOCKELMAN, C. M. BRAAMS, W. W. BUECHNER, AND D. B. GUTHE, *M.I.T.*—Thin CaO targets were prepared by evaporating $CaCO_3$ of isotopic constitution 65 percent $Ca^{42}$ and 35 percent $Ca^{40}$. These targets were bombarded with 7-Mev deuterons accelerated by the MIT–ONR generator. The proton spectrum was recorded with nuclear emulsions in the broad-range magnetic spectrograph at fifteen angles between 10 and 100 degrees. Results for the groups of greatest yield have been obtained. They indicate that both the ground state and 1.00-Mev state in $Ca^{43}$ are fitted by $l_n=3$ Butler curves, if the radius is chosen as $7.5\times10^{-13}$ cm. The state at 0.60 Mev shows a distribution characteristic of $l_n=1$. Results on the $Ca^{41}$ levels are in general agreement with those of Holt and Marsham.[1]

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) **A46**, 565 (1953).

**TA6. The Stripping Reactions $Fe^{56}(d,p)Fe^{57}$ and $Fe^{57}(d,p)Fe^{58}$.*** CHARLES E. MCFARLAND, FRANKLIN B. SHULL, ALEXANDER J. ELWYN, AND BENJAMIN ZEIDMAN, *Washington University.*—Targets of concentrated $Fe^{57}$ (74.6 percent) and natural $Fe^{56}$, both in the form of $Fe_2O_3$, were bombarded with 10-Mev deuterons. Energy spectra of the protons emitted were observed at intervals of 5° in the forward hemisphere with the aid of a proportional counter telescope and an absorber stack of variable thickness. $Q$-values measured for the $Fe^{56}(d,p)Fe^{57}$ reaction are 5.53 (ground state) and 4.24 Mev. Those for the $Fe^{57}(d,p)Fe^{58}$ reaction are 7.09 (ground state), 6.26, 5.15, and 3.72 Mev. By comparison with curves calculated from Butler's theory of stripping reactions,[1] the angular distribution of each of these groups was found to correspond to the capture of neutrons having one unit of orbital angular momentum. The spin of each of the two observed states of $Fe^{57}$ is hence either $\frac{1}{2}$ or $\frac{3}{2}$ and the parity of both states is odd. The spin of each of the observed states of $Fe^{58}$ is 0, 1, 2, or 3, and their parities are all even.

* Supported by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.
[1] S. T. Butler, Proc. Roy. Soc. (London) **208**, 559 (1951).

**TA7. The $O^{18}(d,n\gamma)F^{19}$ Reaction.** H. D. HOLMGREN AND J. W. BUTLER, *Naval Research Laboratory.*—The "gamma-ray threshold" technique[1] of observing energy levels has been applied to the $O^{18}(d,n\gamma)F^{19}$ reaction to study the energy levels of $F^{19}$ in the region of excitation extending from 6.0 Mev to 7.6 Mev. The apparatus was adjusted so as to observe thresholds for gamma rays in the energy range between 4.0 and 7.5 Mev. The only threshold observed was at a bombarding energy of 350 kev, corresponding to a level in $F^{19}$ at an excitation of 6.04 Mev. In addition to a gamma ray of 6.04 Mev, there appears also to be a threshold for a 4.37-Mev gamma ray at 350-kev bombarding energy. A detailed study of the gamma ray spectrum at a bombarding energy of 1.40 Mev confirms our belief that there are no other levels in this region which decay predominantly to any level below the 1.59-Mev level of $F^{19}$, since no gamma rays with an energy higher than 4.5 Mev were observed with an intensity greater than 10 percent of that of the 6.04-Mev gamma ray.

[1] J. W. Butler, Bull. Am. Phys. Soc. **29**, No. 7, 26 (1954), abstract R7.

**TA8. Inelastic Scattering of Protons from $Fe^{54}$ and $Fe^{56}$.†** G. C. PHILLIPS, C. R. GOSSETT, J. P. SCHIFFER, AND P. M. WINDHAM, *The Rice Institute.*—The Rice Institute 180° magnetic spectrometer has been used to study the low-energy levels of iron by bombarding thin targets of separated isotopes* with protons at energies up to 5.7 Mev. Only one level in each isotope was observed for excitation energies below 1.5 Mev. These levels are: $Fe^{54}$, $1.413\pm0.005$ and $Fe^{56}$, $0.845\pm0.005$ Mev. The operation of the spectrometer with the Van de Graaff generator for inelastic scattering measurements will be discussed. The resolution attained is $\Delta\rho/\rho=5\times10^{-4}$. Typical spectra will be presented.

† Supported in part by the U. S. Atomic Energy Commission.
* Supplied by the Oak Ridge National Laboratory.

**TA9. Inelastic Scattering of Protons from Isotopes of Mn, Ni, and Cu.*** J. P. SCHIFFER, P. M. WINDHAM, C. R. GOSSETT, AND G. C. PHILLIPS, *The Rice Institute.*—The Rice Institute 180° magnetic spectrometer has been used to study the low-lying excited states of five isotopes by inelastic scattering of protons. Thin evaporated targets of enriched isotopes[1] were bombarded with protons using energies from 4.6 to 5.7 Mev.

| Isotope | Levels excited Mev |
|---|---|
| $Mn^{55}$ | $0.128\pm0.007$ |
| $Ni^{58}$ | $1.453\pm0.005$ |
| $Ni^{60}$ | $1.329\pm0.005$ |
| $Cu^{63}$ | 0.669, 0.968, 1.326, 1.410, 1.549 all $\pm0.005$ |
| $Cu^{65}$ | No levels observed below 1.5 Mev |

* Supported in part by the U. S. Atomic Energy Commission.
[1] Supplied by the Oak Ridge National Laboratory.

**TA10. The reaction $Ni^{58}(\alpha,\gamma)Zn^{62}$.** H. MORINAGA, *Purdue University.*—The yield of $Zn^{62}$ from the alpha-particle bombardment of natural nickel was studied as a function of the energy of the alpha particles. The 9.3-hour activity due to $Zn^{62}$ (produced by the $(\alpha,\gamma)$ reaction on $Ni^{58}$) was compared with the 38-minute activity of $Zn^{63}$ (produced by the $(\alpha,\gamma)$ reaction on $Ni^{60}$) after chemical separation of zinc from the targets. At alpha-particle energies of 12.0, 13.9, 15.7, and 17.2 Mev, the cross sections are 0.30, 0.49, 0.47, and 0.42 mb, respectively. The order of magnitude is in good agreement with the estimate for the de-excitation of the compound nucleus by electric dipole transitions. The energy dependence of the cross section can be calculated from the statistical theory assuming reasonable level densities. The ratio of the experimental value to the calculated value increases considerably with energy, indicating the reduction of the dipole transition rate at lower energy or some enhancement at the energy corresponding to the giant resonance observed in photonuclear reactions.

**TA11. Gamma Rays from the Proton Bombardment of Cu-63 and Cu-65.*** C. E. WELLER AND J. C. GROSSKREUTZ, *University of Texas.*—Gamma radiation from the bombardment of the separated isotopes Cu-63 and Cu-65 with 1.9-Mev protons was observed by means of a NaI crystal and a 20-channel analyzer. From Cu-63 we detected 0.995-Mev gamma rays, and from Cu-65 1.04- and 0.824-Mev gamma rays, all

presumably due to the inelastic scattering of the protons. The 0.995- and 1.04-Mev radiations correspond to transitions from known excited states of Cu-63 and Cu-65, respectively.[1] The 0.824-Mev gamma ray we assign to either a new level in Cu-65 at 0.824 Mev or to a transition from the 1.04 level to a level at 0.210 Mev. Evidence for the latter level has been previously reported.[2] We have as yet been unable to detect a 0.210-Mev gamma ray. A continous gamma-ray spectrum up to at least 10 Mev was also observed, most probably due to proton capture. Thick target yield curves of the two 1-Mev gamma rays will also be shown. The onset of the $(p,n)$ reaction in Cu-65 is clearly evident just above 2.0 Mev.

* Supported in part by the Office of Scientific Research, Air Research and Development Command.
[1] *Nuclear Data* (United States Department of Commerce, National Bureau of Standards, September 1, 1950).
[2] R. A. Cohn and J. D. Kurbatov, Phys. Rev. **78**, 318 (1950).

**TA12. Gamma-ray Spectrum of $Cd^{113}(n\gamma)Cd^{114}$.*** HENRY MOTZ, *Brookhaven National Laboratory.*—Nine gamma rays superimposed upon an unresolved continuum have been observed from cadmium while being irradiated by slow neutrons. The energies and intensities have been determined by the $K$ x-ray-$K$ photopeak coincidence method, using a thin lens spectrometer[1] with a resolution of 3 percent.

| Energy (kev) | Intensity per neutron captured |
|---|---|
| 557 ±3 | 0.89 |
| 651 ±4 | 0.20 |
| 728 ±5 | 0.07 |
| 803 ±5 | 0.07 |
| 1215 ±8 | 0.10 |
| 1308 ±8 | 0.10 |
| 1388 ±8 | 0.13 |
| 1500 ±15 | 0.05 |
| 1655 ±10 | 0.06 |

These values fit well with the high-energy data of Kinsey and Bartholomew.[2] A discussion of the level scheme for $Cd^{114}$ will be presented.

* Under the auspices of the U. S. Atomic Energy Commission.
[1] Henry Motz, Phys. Rev. **90**, 355(A) (1953).
[2] Kinsey and Bartholomew, Can. J. Phys. **31**, 1051 (1953).

**TA13. $(p,\gamma)$, $(p,\alpha)$, $(p,He_3)$, $(p,t)$, and $(p,Be^7)$ Cross Sections.** B. L. COHEN, H. G. BLOSSER, D. J. COOMBE, G. H. MCCORMICK, AND E. NEWMAN, *Oak Ridge National Laboratory.*—Activation cross sections for several $(p,\gamma)$, $(p,\alpha)$, $(p,He_3)$, and $(p,t)$ reactions were measured using 22-Mev protons from the Oak Ridge National Laboratory 86-inch cyclotron. Reduced energies were obtained with absorbers; radiochemical processing was used in most cases. $(p,\gamma)$ cross sections vary only slightly with bombarding energy and target mass; this is strongly contrary to expectations from compound nucleus interaction. The absolute cross sections (~1 mb) are consistent with a direct interaction interpretation. $(p,\alpha)$ cross sections are in general agreement with the predictions of statistical theory; this includes cases for $A=54-202$ and is in sharp contrast to the findings of Paul and Clarke[1] for $(n,\alpha)$ reactions. $(p,t)$ and $(p,He_3)$ cross sections are also in good agreement with the predictions of statistical theory; this indicates that, after correcting for Coulomb and energetic effects, emission of tritons, $He^3$ ions, and alpha particles in nuclear reactions is just as probable as emission of neutrons or protons. A search for $(p,Be^7)$ reactions was made with 30-Mev protons from the Berkeley linac.[2] Preliminary results indicate $\sigma(p,Be^7)<0.1$ mb in fluorine, oxygen, and sodium.

[1] E. B. Paul and R. L. Clarke, Can. J. Phys. **31**, 268 (1953).
[2] We are greatly indebted to Dr. L. Alvarez for the use of the University of California Radiation Laboratory linear accelerator.

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SATURDAY MORNING AT 9:30

NBS, East Building

(R. T. BIRGE presiding)

## *Invited Papers on Thermodynamics and Cryogenics*

**U1. Carnot's Concept of Entropy, and Modern Presentations of Thermodynamics.** V. K. LA MER, *Columbia University.* (30 min.)

**U2. New Definition of the Kelvin Scale Adopted by the Tenth General Conference on Weights and Measures.** F. G. BRICKWEDDE, *National Bureau of Standards.* (30 min.)

**U3. The Theory of Liquid Helium.** R. P. FEYNMAN, *California Institute of Technology.* (40 min.)

**U4. Structure of the Intermediate State in Superconductors.** A. L. SCHAWLOW, *Bell Telephone Laboratories.* (30 min.)

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SATURDAY MORNING AT 9:30

Exhibit Hall II

(J. W. DAVISSON presiding)

## *Various Topics in Solid-State Physics*

**UA1. Low Frequency Vibrational Spectrum of F.C.C. Lattice.** L. SALTER, *Wabash College* (introduced by F. E. Throw).—Houston's method[1,2] is applied to the problem of determining the normal mode distribution function for the face-centered cubic lattice in the low-frequency limit. The method yields explicit expressions for the coefficients $a_i$, $g(\omega)=a_1\omega^2+a_2\omega^4+a_3\omega^6\cdots$, in terms of the force parameters occurring in the dynamical matrix for the problem. Experimental values of $c_{11}$, $c_{12}$, and $c_{44}$ are used to discuss the variation of the equivalent Debye $\Theta$ in the low-temperature range for several substances of interest.

[1] W. V. Houston, Revs. Modern Phys. **20**, 161 (1948).
[2] E. Bauer, Phys. Rev. **92**, 58 (1953).

**UA2. On The Frequency Spectrum of a One-Dimensional Isotopic Crystal Mixture.*** ROBERT J. RUBIN AND B. A.

FLEISHMAN, *Applied Physics Laboratory.*—We use a perturbation method to obtain the first- and second-order corrections to the vibration frequencies of a one-dimensional crystal composed of a random arrangement of two isotopes of mass $M_A$ and $M_B$ in the proportions $P:(1-P)$. The zeroth-order approximation is chosen to be a uniform crystal composed of particles with the average mass $M=M_AP+M_B(1-P)$. The average first-order correction is zero where the average is taken over all possible arrangements of the isotopes. The average second-order correction to the square of the $i$th frequency is

$$\omega_i^{(2)}=\frac{3k}{8M}P(1-P)\sin^4\frac{i\pi}{2(N+1)}\times\left\{\frac{\cos i\pi/(N+1)}{(N+1)\sin^2 i\pi/(N+1)}+\frac{1}{i\pi\sin i\pi/(N+1)}\right\},$$

where $k$ is the force constant and $\epsilon^2=(M_A-M_B)^2/4M^2$. The second-order correction as might be expected diverges at high frequencies ($i\sim N$). The existence of this divergence has a bearing on a perturbation calculation of the zero-point energy of a one-dimensional isotopic crystal mixture.

* This work was supported by the Bureau of Ordnance, Department of the Navy.

**UA3. On the Optical Properties of Solids.** HERBERT B. ROSENSTOCK, *Naval Research Laboratory.*—Accepted first-order theory asserts that a nonvanishing dipole moment is associated with only those vibrations of a lattice whose propagation vector is zero.[1] This result is based on the use of the so called "cylic" boundary conditions in the normal mode analysis of the lattice. Application of exact boundary conditions[2] to the problem indicates, however, that the dipole moment is a quasi-continuous and ordinarily nonvanishing function of the propagation vector with a strong peak at the point predicted by first-order theory. It follows that the $3n-3$ (or fewer) sharp lines which make up the first-order infrared absorption spectrum (also the reflection- and the first-order Raman spectrum)[3] of a crystal with $n$ atoms per unit cell should be broadened and that "absorption edge" effects should be observed at the frequencies at which singularities[4] appear in the frequency spectrum of the solid.

[1] M. Born and M. Goeppert-Mayer, *Handbuch der Physik* (Verlag Julius Springer, Berlin, Germany, 1933), **24/2**, 623, Sec. II.
[2] M. Born, Proc. Phys. Soc. (London) **54**, 362 (1942).
[3] M. Born and M. Bradburn, Proc. Roy. Soc. (London) **A188**, 161 (1947).
[4] L. van Hove, Phys. Rev. **89**, 1189 (1953); H. B. Rosenstock, Phys. Rev. **97**, 290 (1955).

**UA4. Change in Length of Alkali Halide Crystals Caused by X-Ray Irradiation.*** LAN-YING LIN AND B. R. RUSSELL, *University of Pennsylvania.*—Potassium and sodium chloride crystals (about 12 mm×7 mm×1.5 mm) at room temperature were irradiated with x-rays in a thermostated enclosure regulated to $10^{-2}$ °C. The crystals were about 2½ inches from the x-ray-tube beryllium window. The change in length of the largest dimension of the crystal was measured during the irradiation by a capacitance-type dilatometer with sensitivity $10^{-6}$ cm. The $F$ center density calculated from the increase in length per unit length (assuming one ion pair at the surface for each pair of lattice vacancies) agreed within 5 percent with the number of color centers determined subsequently by optical absorption measurement. For example: $\Delta l/l=6.1\times10^{-7}$, $n$(calculated) $=4.1\times10^{18}$ cm$^{-3}$, $n$(optical, colored portion) $=3.9\times10^{18}$ cm$^{-3}$ for NaCl; $\Delta l/l=1.36\times10^{-6}$, $n$(calculated) $=6.6\times10^{18}$ cm$^{-3}$, $n$(optical) $=6.7\times10^{18}$ cm$^{-3}$ for KCl. These crystals were uncolored in about 30 percent of their volume as they were larger than the x-ray beam. Using a slightly smaller crystal to get uniform coloration throughout the whole crystal, $\Delta l/l=4.3\times10^{-7}$, $n$(calculated) $=2.1\times10^{18}$ cm$^{-3}$, $n$(optical) $=2.0\times10^{18}$ cm$^{-3}$ for KCl.

* This research was supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

**UA5. X-Ray Diffraction Studies of Radiation Damage of Germanium Single Crystal.*** SIGMUND WEISSMANN AND ROGER CHANG, *Rutgers University.*—A germanium single crystal (impurities 1 part in $10^9$, resistivity 35 ohm-cm) was acid-cut into two halves. One half of the crystal was subjected to neutron irradiation at a temperature of 160–200°C. The slow neutron flux was measured to be $1.43\times10^{18}$ n.v.t., the fast neutron flux was estimated to be half this value. Rocking curves were performed for both the irradiated and unirradiated specimens using a calcite crystal as first crystal and testing the specimens in the (1, −1) position with CuK$\alpha_1$ radiation. The halfwidths for the (111) reflection obtained were: unirradiated specimen 56 seconds of arc; irradiated specimen 3½ minutes of arc. The irradiated germanium crystal exhibited also considerable diffuse scattering. Precision lattice parameter determination yielded: unirradiated specimen, $a_0=5.657_7A$; irradiated specimen $a_0=5.659_2A$. The increase in lattice parameter (about 0.02 percent) for the irradiated specimen is insufficient to account for the observed 3-fold increase in halfwidth. An explanation of the observed phenomena is being advanced.

* Work supported by the U. S. Atomic Energy Commission.

**UA6. Slip Systems and Creep in Oxide Crystals.** J. B. WACHTMAN, JR., AND L. H. MAXWELL, *National Bureau of Standards.*—Single crystals of periclase, rutile, and sapphire deform by slip at temperatures above one-half their absolute melting temperature. Slip systems are (100), (110), and (111) with [1$\bar{1}$0] in periclase, (011) and (201) in rutile, and (0001) with [11$\bar{2}$0] in sapphire. Temperature of about 1600°C is required for deformation other than slip on the (0001) plane. There is a rather well-defined stress required to cause creep to begin in sapphire. This creep yield stress is 780 kg/cm$^2$ resolved shear stress at 900°C and falls monotonically to about 130 kg/cm$^2$ at 1400°C. Sapphire containing about 0.75 percent chromia has a value about twice that of pure sapphire at 1300°C. The typical creep curve for sapphire under constant load has a distorted "$S$" shape. Creep begins very slowly at first, rises to a maximum rate, and finally falls off to a very slow rate. At 1300°C a final stage of fast creep apparently leading to failure sometimes occurred. The modulus of rupture of sapphire measured in short-time tests rises from about 3800 kg/cm$^2$ at 800°C to about 6200 kg/cm$^2$ at 1000°C. This is interesting as plastic deformation in long-time tests begins about 900°C.

**UA7. Relationship between Activation Energy for Slip in Crystalline Solids and Applied Stress Based on a Dislocation Model.** ROGER CHANG, *Rutgers University.*—Attempts have been made by many investigators[1-3] to find a theoretical relationship between activation energy for slip in crystalline solids and applied stress with only limited success. The present theory assumes that the activation energy for the movement of a dislocation line against an array of obstacles is equal to the maximum work done by the tension in the dislocation line to move the dislocation against the obstacle one interatomic distance in the slip direction. A simple derivation yields $U=-(Gb^3/4\pi)\ln(\tau/\tau_0)$, where $U$ is the activation energy, $G$ shear modulus, $b$ Burger's vector, ln natural logarithm, $\tau$ applied shear stress, $\tau_0=(Gb/4\pi\Omega_0)$, $\Omega_0$ being the effective radius of that region around the dislocation line within which Hooke's law fails ($\Omega_0\cong2b$). The agreement between theory and experimental data is remarkably good. Further work based on the theory is being carried on by the author to develop a generalized theory of creep in crystalline solids.

[1] F. R. N. Nabarro, Advances in Phys. **1**, 336 (1952).
[2] A. H. Cottrell and B. A. Bilby, Proc. Phys. Soc. (London) **62A**, 49 (1949).
[3] T. Yokobori, J. Physiol. Soc. Japan **7**, 44 (1952).

**UA8. Cavity Formation in Iron Oxide.*** D. W. JUENKER,† R. A. MEUSSNER, AND C. E. BIRCHENALL, *Princeton Uni-*

*versity.*—A study has been made of the formation of oxide scale on iron in an oxygen atmosphere at temperatures above 700°C. Apart from the expected behavior,[1,2] there was observed a phenomenon not reported by previous investigators; when an iron sample is oxidized to an "FeO" composition and permitted to homogenize in argon, there may be found within the oxide a cavity, of geometry nearly identical with that of the original iron sample, surrounded by oxide walls of uniform thickness, and containing no more than a residual filament of the original specimen. From this behavior and other evidence, one may infer that the iron core sometimes separates completely from the surrounding oxide, with iron transport continuing despite the absence of substantial oxide-iron contact. The mechanism of this transport of iron from the separated core to the interior surface of the oxide is in doubt.

* This research was supported by the United States Air Force, through the Office of Scientific Research of the Air Research and Development Command.
† Presently with the Department of Physics, University of Notre Dame.
[1] Davies, Simnad, and Birchenall, Trans. Am. Inst. Mining Met. Engrs. 191, 889 (1951).
[2] Dunnington, Beck, and Fontana, Corrosion 8, 2 (1952).

**UA9. Energy Transport in the Scintillation Process.*** E. R. HARDWICK† AND W. G. MCMILLAN, *University of California at Los Angeles.*—In scintillation solutions, the transfer of excitation energy from solvent to solute (phosphor) molecules theoretically may occur through either photons or excitons. Against a prevalent thesis that *all* transfer occurs via photons it may be argued that (a) transfer has been observed using *UV* excitation, even when solvent-emission and phosphor-absorption bands do not appreciably overlap; (b) the decay time of a pulse ($\sim 10^{-9}$ sec) seems rather too short to permit an appreciable number of photon emission-reabsorption steps. While the exciton theory appears to avoid these particular difficulties, there is little doubt but that some effects, such as the transfer through glass observed by Ageno and Querizoli,[1] require the photon mechanism. Certainly at least the reabsorption of scintillation photons constitutes a mechanism of (long-range) energy transfer. We have studied experimentally three aspects of the scintillation process: (a) quenching and self-quenching of $\alpha$-particle induced scintillations; (b) transfer distances, recorded photographically following Ageno; and (c) destruction of the surface of anthracene crystals by $\alpha$-particles, monitored by the consequent decline in scintillation efficiency. The bearing which these measurements have upon the questions raised above will be discussed.

* This work was assisted by a grant in aid from the Institute for Geophysics, University of California at Los Angeles.
† Present address: National Research Council, Ottawa 2, Canada.
[1] M. Ageno and R. Querizoli, Nuovo Cimento 9, 196, 282 (1952).

**UA10. Hall Effect and Resistivity Study of Photoconducting PbS Films.** JOSEPH F. WOODS, *U. S. Naval Ordnance Laboratory, and Catholic University of America.*—Hall coefficient ($R$) and resistivity ($\rho$) have been measured on chemically-deposited PbS photoconducting films* under varying degrees of illumination sufficient to produce current increases of 3 to 167 percent of the dark current. $R$ is measured by a $d$–$c$ method utilizing a vibrating reed electrometer and recorder. Values of the ratios $\Delta R/R_0$ and $\Delta\rho/\rho_0$ are accurate to within 3 percent, where $R_0$ and $\rho_0$ are the dark values of $R$ and $\rho$ respectively, and $\Delta R$ and $\Delta\rho$ are the corresponding changes produced by the illumination. It is found that under a given value of illumination $\Delta R/R_0$ is equal to $\Delta\rho/\rho_0$ within 7 percent. $R$ is basically a measure of the number of carriers within the crystallites while $\rho$ depends both on the number of carriers and on the mobility which is limited by barriers in the film. Hence, these results suggest that the mobility does not change significantly under illumination and that the photoconductive effect is caused directly by an increase in the number of carriers.

* The author wishes to acknowledge the cooperation of the Eastman Kodak Company in preparing the lead sulfide films used in these studies.

**UA11. *The Absorption of Alkali-Halides in the Far Ultra-Violet.** J. R. NELSON, J. G. SIEGFRIED, AND P. L. HARTMAN, *Cornell University.*—To augment photoconductivity measurements to be made on NaCl and KCl, the absorption spectrum of these substances has been obtained at two temperatures, in the region from 900A to 1750A. Measurements on evaporated films by transmission and on bulk crystals by reflectivity are in fair agreement but not in strict accord with the data of Schneider and O'Bryan. Curves will be shown illustrating new regions of the spectrum and points of difference with previous measurements. The effect of narrowing and resulting appearance of fine structure of the presumed exciton peak at low temperature will be presented.

* Supported in part by the Office of Naval Research.

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## SATURDAY MORNING AT 9:30

## Continental Room

## (M. GOLDHABER presiding)

## *Radioactive Substances, I*

**V1. Gamma Rays from $P^{34}$, $Cl^{34}$, and $P^{30}$.*** E. BLEULER AND H. MORINAGA, *Purdue University.*—The gamma rays following the beta decays of $P^{34}$, $Cl^{34}$, and $P^{30}$ were investigated with NaI scintillation spectrometer and a twenty-channel analyzer. In addition to the two known $2^+$ levels at 2.16 and 3.24 Mev in $S^{34}$, another $2^+$ level was found at 3.9 Mev. The *ft* values of the beta decays to the first and the third excited state are lower than average from $P^{34}$ and higher than average from the $3^+$ isomeric state of $Cl^{34}$. For the second excited state the situation is reverse. The decay from $P^{30}$ to the first excited state of $Si^{30}$ was found to be slower than an average allowed transition. The results are discussed in terms of mixed configurations; appreciable mixing is suspected to exist in the $0^+$ ground state of $S^{34}$ (and $Cl^{34}$) which possibly explains the unusual $T=1$ ground state of $Cl^{34}$.

* Supported by U. S. Atomic Energy Commission.

**V2. Radioactive Decay of $Ca^{47}$.*** L. J. LIDOFSKY, N. BENCZER, AND V. K. FISCHER, *Columbia University.*—The results of several recent investigations[1–3] on the decay properties of $Ca^{47}$ are in considerable disagreement as to the maximum energies of the negatron groups, the number of associated gamma rays and the half-lives. We have reinvestigated the decay in an attempt to resolve these disagreements and to understand certain of its features. The $Ca^{47}$ half-life is found to be $4.7\pm0.2$ days and a beta spectrum is

observed which can be resolved into groups of maximum energy 1.92±0.02 Mev and 0.65±0.03 Mev. Gamma rays of 1.31±0.02 Mev, 0.82±0.02 Mev, and 0.48±0.02 Mev are found. Gamma-gamma coincidences are observed only between the 0.82 Mev and the 0.48 Mev radiations. We see no other gamma rays unambiguously attributable to $Ca^{47}$. The results of these investigations and others in progress on the $A=47$ isobars will be discussed.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] Luis Marquez, Phys. Rev. 92, 1511 (1953).
[2] Cork, LeBlanc, Brice, and Nester, Phys. Rev. 92, 367 (1953).
[3] Aten, Grenell, and Van Dijk, Physica 19, 1049 (1953).

**V3. Decay of $Sc^{44}$.*** J. W. BLUE AND E. BLEULER, *Purdue University.*—The decay of $Sc^{44}$ has been reinvestigated using a magnetic-lens spectrometer adapted to coincidence measurements. The fraction of transitions going by electron capture has been measured to be 0.06±0.01, in agreement with theory. With this branching ratio the total conversion coefficients of the 270-kev isomeric transition and of the 1.16-Mev gamma ray in $Ca^{44}$ are 0.132±0.002 and 6.36±0.13×$10^{-3}$ respectively. This indicates an $M4$ or $E4$ transition for the 270-kev gamma ray and an $E2$ transition for the 1.16-Mev gamma ray. The continuous electron spectrum, reported by Bruner[1] to accompany 4 percent of the positron decays, has been studied in coincidence with the nuclear gamma ray and with the positrons. The intensity was observed to be very dependent on the thickness of the source and backing. Using vacuum evaporated sources on 0.6 mg/cm² Al backing, the electron intensity between 30 and 150 kev was found to be ¼ of that previously reported. The coincidence measurements show that ¾ of these electrons are not in coincidence with the full-energy nuclear gamma ray and hence are created by the gamma ray.

* Supported by the U. S. Atomic Energy Commission.
[1] J. A. Bruner, Phys. Rev. 84, 282 (1951).

**V4. Inner Bremsstrahlung from $V^{49}$.** R. W. HAYWARD AND D. D. HOFFES, *National Bureau of Standards.*—The x-radiation and inner bremsstrahlung from the electron capturing $V^{49}$ have been studied by means of an argon-methane proportional counter and a well-type sodium-iodide scintillation spectrometer. The observed internal bremsstrahlung spectrum is corrected for background, energy resolution, Compton and escape electrons, gamma-ray detection and geometrical efficiency of the crystal, and source-absorption effects. The spectrum may be essentially accounted for over most of the energy range by the theory of Glauber and Martin[1] incorporating $p$-electron capture and Coulomb effects. The total disintegration energy of $V^{49}$ as determined from the spectrum is 610±10 kev. A recent determination of the half-life of 334±20 days by Lyon[2] leads to a $\log ft=6.16\pm0.03$, a value consistent with other allowed spectra with transitions within the $f_{7/2}$ shell.

[1] R. J. Glauber and P. C. Martin, Phys. Rev. 95, 572 (1954).
[2] W. S. Lyon, Phys. Rev. 97, 121 (1955).

**V5. The Internal Conversion Coefficient of Cr—51.** Z. O'FRIEL AND A. H. WEBER,* *Saint Louis University.*—The internal conversion coefficient of $V^{51}$ (parent, $Cr^{51}$) was measured (using a thin lens $\beta$-ray spectrometer) employing the Compton electron spectrum for determination of the number of unconverted nuclear photons,[1] following the Thomas-Lauritsen analysis.[2] The value of $\alpha_K$ is (1.38±0.13)×$10^{-4}$. This value compares with 1.5×$10^{-4}$ of von D. Maeder, *et al.*[3] who used a scintillation detector for the measurement of atomic x-rays and nuclear photons. These values correspond to an $M1$ transition in the Rose-Goertzel tables. Since $Cr^{51}$ decays by $K$-capture to the ground state of $V^{51}$, the Compton electron method is particularly applicable.

* Supported in the initial phases of the work by the U. S. Atomic Energy Commission.
[1] Sturcken, O'Friel, and Weber, Phys. Rev. 93, 1053–1056 (1954).
[2] R. G. Thomas and T. Lauritsen, Phys. Rev. 88, 969–986 (1952).
[3] von D. Maeder, Preiswelk, and Steinemann, Helv. Acta Phys. 25, 461–463 (1952).

**V6. The Decay of $Rh^{104}$ and $Rh^{104m}$.*** M. E. BUNKER, J. P. MIZE, AND J. W. STARNER, *Los Alamos Scientific Laboratory.*—The radiations of $Rh^{104}$ (44 sec) and $Rh^{104m}$ (4.3 min) have been investigated with $\beta$- and $\gamma$-scintillation spectrometers and a magnetic lens. The dominant radiation of $Rh^{104}$ is the well-known 2.5-Mev ground-state $\beta$ transition (98.5 percent). $\beta$-$\gamma$ coincidence studies have revealed two other $Rh^{104}$ $\beta$ groups with energies and intensities of ~1.9 Mev (1.4 percent) and ~0.7 Mev (0.08 percent). Associated with the lower-energy $\beta$ groups are $\gamma$ rays of energy 0.556 and 1.24 Mev. These two gammas are in coincidence. Although $Rh^{104m}$ decays predominantly by gamma emission to $Rh^{104}$, it is also $\beta$ unstable (~0.1 percent of the disintegrations), giving rise to $\gamma$ transitions in $Pd^{104}$ of energy 0.556, 0.74, 0.78, and 1.53 Mev. $\gamma$-$\gamma$ coincidence studies indicate the existence of additional $\gamma$ rays of energy ~0.92 and ~1.34 Mev which are presumably also associated with the decay of $Rh^{104m}$. Possible spin assignments for the levels of $Pd^{104}$ will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**V7. Decay of Neutron Deficient Rhodium Isotopes.*** DONALD J. FARMER, *University of Washington.*—Observation of the decay of internal conversion electrons from active rhodium using a beta-ray spectrometer with sources prepared from the rhodium fractions of proton- or deuteron-bombarded ruthenium, and additional studies with a NaI (Tl) scintillation coincidence spectrometer using sources prepared by proton bombardment of natural and separated isotopes of ruthenium reveals radiations having the following characteristics: Rh mass ≤99, half-life 15.0±0.2 days, gamma rays 0.086 Mev ($K/L/M\approx25/5/1$) and 0.353 Mev, coincidences between these radiations and with annihilation radiation; Rh mass <102, half-life 5±1 years, gamma rays 0.127 Mev ($K/L\approx8$) and 0.198 Mev, coincidences between these radiations, no coincidences with annihilation radiation. These radiations were previously attributed to $Rh^{102}$ (220 day).[1,2] The mass assignments of 4.5 day $Rh^{101}$ and 21 hour $Rh^{100}$ are confirmed, as are the assignments of the higher-energy gamma radiations of $Rh^{102}$. Gamma-ray coincidence studies have been made on the latter isotope.

* Supported in part by the U. S. Atomic Energy Commission.
[1] L. Marquez, Phys. Rev. 95, 67 (1954).
[2] D. B. Kochendorfer and D. J. Farmer, Phys. Rev. 96, 853A (1954).

**V8. Attenuation of the $Cd^{111}$ Directional Correlation in Liquid $In^{111}$ Sources.** R. M. STEFFEN, *Purdue University.*—Directional Correlation measurements[1] on viscous liquid sources of $In^{111}$ indicated the presence of a small but not negligible attenuation of the $Cd^{111}$ gamma correlation in dilute aqueous solutions of In salts. The attenuation effect is due to the interaction of the nuclear quadrupole moment in the first excited $Cd^{111}$ state with the rapidly fluctuating fields which are present in the liquid. This time-dependent interaction is characterized by a parameter $\lambda_2$. Measurements of the directional correlation of the $Cd^{111}$ gamma rays as a function of the delay-time between the emission of the first and the second gamma ray enabled us to measure $\lambda_2$ directly for different liquid sources. In dilute aqueous solutions $\lambda_2=(6\pm1)\times10^8$ $sec^{-1}$. Viscous sources (aqueous solutions of $InCl_3$ +glycerin) show considerably larger values of $\lambda_2$; however, $\lambda_2$ does not increase as rapidly as the macroscopic viscosity of the liquid. The unperturbed directional correlation of the $Cd^{111}$ gamma cascade, as obtained from these measurements, is: $W(\theta)=1-(0.18\pm0.01)P_2(\cos\theta)$.

[1] P. B. Hemmig and R. M. Steffen, Phys. Rev. 92, 832 (1953).

**V9. A Fast Favored First Forbidden Beta Transition.*** MICHAEL J. GLAUBMAN, *Princeton University.*—The ground state of $Sb^{122}$ is known to be $2^-$; the ground state of the even-even $Sn^{122}$ nucleus is presumably $0^+$. The transition between

the two states is parity favored and therefore unique (Tensor), and the $K/\beta^+$ ratio depends only on the energy and certain well-defined electronic wave functions.[2] We have measured the positron intensity (by measuring the annihilation radiation in a calibrated source) and compared it with the intensity of the $K$ capture to the ground state as determined in a previous experiment.[3] Our preliminary results are: $K/\beta^+ = 300 \pm 130$; $W_0 = 2$ $(mc^2)$; $\log(W_0^2-1)ft = 9 \pm 0.15$. The $\log ft$ value indicates that the positron decay is speeded up by a factor of 10 compared to the negatron decay.[1] This fact can be explained in terms of the purity of configurations of magic nuclei and the favorable configuration of $Sb^{122}$ $(g_{7/2}h_{11/2})$ for this type of transition $(\Delta J = 2, \Delta L = 1)$.

* Supported by the Atomic Energy Commission and The Higgins Fund.
[1] M. J. Glaubman and F. R. Metzger, Phys. Rev. **87**, 203 (1952).
[2] R. E. Marshak, Phys. Rev. **61**, 431 (1942).
[3] M. J. Glaubman, to be published in the Phys. Rev.

**V10. Radiations from $_{50}Sn^{125}$ (9.7 *d* and 9.5 *m*).*** S. B. BURSON, J. M. LEBLANC, AND D. W. MARTIN, *Argonne National Laboratory*.—The radiations from $_{50}Sn^{125}$ (9.7 *d* and 9.5 *m*) have been studied using the scintillation coincidence spectrometer and the decay scheme deduced. Enriched $Sn^{124}$ was irradiated with reactor neutrons and chemically purified. From the NaI(Tl) pulse-height distribution, the presence of seven gamma rays associated with the 9.7-day activity is concluded. These have energies: $1.98 \pm 0.02$, $1.41 \pm 0.02$, $1.07 \pm 0.01$, $0.90 \pm 0.01$, $0.81 \pm 0.01$, $0.47 \pm 0.01$, and $0.34 \pm 0.01$ Mev. An anthracene crystal was used for beta-ray detection. The aluminum-absorption curve of the total beta spectrum shows, in addition to a predominant component of about 2.3 Mev, a weak low-energy branch. Coincidence-absorption curves taken with selected gamma rays show this inner spectrum itself to be complex. Two components of ~0.4 Mev and ~1.3 Mev are so resolved. The foregoing results, together with gamma-gamma coincidence measurements, lead to a decay scheme for the 9.7-day activity believed to be unique. Four excited states in the $Sb^{125}$ nucleus with energies 1.07, 1.41, 1.88, and 1.97 Mev are shown to exist. In the 9.5-m activity, a weak gamma ray of 1.41 Mev is observed in addition to the known 0.326-Mev transition.

* Work done under auspices of U. S. Atomic Energy Commission.

**V11. Radioactive Decay of $Cs^{134}$.** H. H. FORSTER AND J. S. WIGGINS, *University of Southern California*.—The beta- and gamma-ray spectra of (2.3*y*) $Cs^{134}$ have been investigated with a double-thin lens beta-ray spectrometer of 1.5–2.5 percent resolution and a NaI scintillation spectrometer with a single-channel pulse-height analyzer. The source material was CsCl in acid solution obtained from Oak Ridge. An analysis of the beta spectrum showed evidence of four beta groups with approximate endpoint energies of 87, 220, 405, and 655 kev. Gamma lines obtained through internal and external conversion had energies of 475, 562, 569, 604, 662, 796, 802, 1036, 1170, 1368, and 1401 kev. No definite evidence for the 202 kev gamma mentioned by Cork[1] has been observed. Details of the spectrum will be presented, and the decay scheme will be discussed.

[1] Cork, LeBlanc, Nester, Martin, and Brice, Phys. Rev. **90**, 444, (1953).

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## SATURDAY MORNING AT 9:00

Caribar Room

(E. MONTROLL presiding)

### *Theoretical Physics, IV*

**VA1. Application of Operator Calculus to Irreversibility.** U. FANO, *NBS*.—A small system $A$ interacting with a large system $B$ experiences irreversible effects, analyzed conveniently[1] by Feynman's operator calculus. To describe the state of $A$ we consider the Heisenberg representation $\mathfrak{F}(t) = \exp(iHt) \times F \exp(iHt)$ of operators $F$ acting on $A$ only, and average it over the initial state of $B$ ($\mathfrak{F}(t)$ operates on $B$ through $H = H_A + H_B + V$). An improved version of an earlier[1] formula is now presented:

$$\langle \mathfrak{F}(t) \rangle_B = F \exp \int^t dt' \{ i[H_A + \langle V \rangle_B, I] - \int^{t'} du \langle [\bar{\mathfrak{V}}(-u), (\bar{\mathfrak{V}}, I)] \rangle_B + \cdots \},$$

where operators on left of $I$ act left of $F$. This equation is exact and displays the qualitative aspects of the problem. $\langle \mathfrak{F}(t) \rangle_B$ varies by infinitesimal transformations $\exp dt' \{ \cdots \}$ which operate not in succession but interlocked because $\bar{\mathfrak{V}}(-u)$ acts at $t'-u$ instead of $t'$. The time variations of $\langle \mathfrak{F}(t) \rangle_B$ obey a first-order differential equation only if this interlocking can be discounted in view of short life of autocorrelations and of other circumstances.

[1] U. Fano, Phys. Rev. **96**, 869 (1954).

**VA2. Green's Function for Heat Conduction-Convection Problems with Given Motion of the Boundaries.** H. KURT FORSTER, *University of California*.—The equation for combined heat conduction and convection in an incompressible fluid contains the explicitly time varying term $v(r,t)\ \mathrm{grad}\, T$; consider conditions $T = 0$ or $\mathrm{grad}\, T = 0$ along boundaries which may move; general methods are hardly developed for such problems. We show that a solution, to any desired degree of accuracy, may be obtained along these lines: Subdivide $t$ into intervals $t_1 t_2 \cdots t_n$; let the temperature distribution at $t_i$ be $T_i(r')$ and $G_i[r,r', (t_{i+1}-t_i)]$ the known Green's function for the pure heat-conduction problem for the domain at $t_i$. Solve the pure conduction problem from $t_i$ to $t_{i+1}$ by $\Theta(r) = \int G_i \cdot T_i dr'$; then $T_{i+1}(r') = \Theta[r' - h(r')]$, where $h(r)$ represents the fluid displacement (convection) in time $(t_{i+1}-t_i)$, gives an approximation to the temperature distribution at $t_{i+1}$. Let $P_n(r,t)$ be the result of this process applied successively to the $n$ intervals, and let the initial temperature be an instantaneous unit source, the convergence of $P_n$, as $n \to \infty$, to the exact Green's function of the heat conduction-convection problem is then assured on physical grounds and the boundary conditions remain satisfied throughout. This method was applied to an actual problem;[1] a mean for $P_1$ (between the two possible paths leading to $P_1$) gave good agreement with experiment.

[1] H. K. Forster, J. Appl. Phys. **25**, 1067 (1954).

**VA3. Numerical Solution of the Integral Transport Equation.** DANIEL SCHIFF, *Westinghouse Electric Corporation*.—The transport equation for particles which interact only with the constituents of a relatively dense medium, and not with one another, is expressed in the form of an inhomogeneous linear integral equation. The unknown function in this equation is the directional flux, or in an alternate formulation, the

$i$th generation of directional birth-rate density. There is in the general case a quadruple integral over the space, angle, and energy variables, the kernel being a product of a cross section, an exponential attenuating factor, and a scattering function. The equation is made amenable to computation by employing discrete variables and replacing the integrals with sums over the space lattice, angular divisions, and energy groups. All physical processes may be included, the approximation being only in the size of the above intervals. With the aid of an electronic digital-computer multienergy group, multiregion problems have been calculated which include capture, fission, elastic, and inelastic scattering of neutrons and photoelectric absorption, pair production, and Compton scattering of gamma rays. Simple cases have been calculated for comparison with analytic solutions of the differential integral form of the transport equation, and they yield satisfactory results.

**VA4. Asymptotic Spatial Trend of Electron Penetration.** L. V. SPENCER, *NBS.*—The equation describing electron penetration in the continuous slowing-down approximation[1] is reduced to an interlinked system of ordinary differential equations by a Fourier transform in the spatial coordinate and a Legendre transform in angle. In an approximation suited to deep penetration this system reduces further to a partial differential equation having the simple but apparently nonseparable form of a Schrodinger oscillator equation with time-dependent force constant. This equation is in fact separable and has both eigenfunction and point solutions. The point solutions are of most interest and yield the desired deep penetration spatial trend. In the limit of small-energy losses, the point solutions express analytically the summation of the series solutions of Yang.[2] The treatment of this schematic equation can be generalized to yield a method for solving the more realistic linked system of ordinary differential equations. This approach supports and complements a theory recently submitted by the author to the Physical Review.

[1] H. W. Lewis, Phys. Rev. **78**, 526 (1950).
[2] C. N. Yang, Phys. Rev. **84**, 599 (1951).

**VA5. Diffusion Equation of Nucleonic Component of Cosmic Rays.*** S. OLBERT, *M.I.T.*—A linear integro-differential equation of the type:

$$\frac{\partial N(E,x)}{\partial x}=\frac{-1}{\lambda}N(E,x)+\frac{1}{\lambda}\int K(E,E')N(E',x)dE'+Q(E,x)$$

is investigated theoretically with particular reference to the diffusion of the nucleonic component of high-energy cosmic rays in the atmosphere. The kernel function $K(E,E')$ is chosen so as to incorporate the basic features of Fermi's model of multiple production of meson and (possibly) antinucleons. It is shown that, using reasonably simplified forms of $K(E,E')$, one can find general analytic solution of the above equation. The results obtained are compared with the experimental data.

* This work is supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**VA6. Exchange in the Thomas-Fermi-Dirac Model.*** W. G. MCMILLAN, *University of California at Los Angeles and The RAND Corporation.*—In the statistical model of the atom at zero temperature, the maximum local electron-momentum $P$ is related to the electrostatic potential $V$ by $P^2/2m-\lambda e^2P/\pi\hbar=eV+\mu$, where $\mu$ is the electron chemical potential. The coefficient $\lambda$ is zero for the Thomas-Fermi (TF) case, and unity for the Dirac (TFD) modification. March has recently given compelling arguments for interpreting the zero-pressure TFD atom (which has a finite radius) as a constituent of a metallic phase rather than of a dilute gas, and has cited the atomic radii of the alkali metals in support. Generally, however, this model predicts much too large atomic volumes. The Dirac exchange correction is calculated using plane waves, and thus assumes that the electrons involved in the exchange come from regions of the same density, and therefore same $P$. Actually, the electron density within a normal atom changes markedly over (radial) distances comparable to the electron wavelength. Near the atomic boundary this has a most pronounced effect on $P$ and thus on the predicted normal volume. Assuming the exchange correction to be of the Dirac form, but with $\lambda P$ in place of $P$, $\lambda$ has been determined from Latter's solutions so as to give agreement with experimental atomic volumes. The resulting values of $\mu(=1.29\lambda^3$ ev), then agree semiquantitatively with experimental photoelectric work functions.

[1] R. Latter (to be published).

**VA7. A Variant on the Yang Lee Theory of Condensation.** M. B. LEWIS AND A. J. F. SIEGERT, *Northwestern University.*—The pressure defined in the work of Yang and Lee[1] is not the average pressure in the grand canonical ensemble, but is defind by averaging the latter once more over all volumes smaller than the volume of the systems in the grand canonical ensemble.[2] While there is little doubt that these two definitions become equivalent in the limit of infinite volume, a rigorous proof of this equivalence would have to be based again on properties of the *canonical* partition function such as van Hove's theorems.[3] We have, therefore, made more rigorous a variant of the Yang Lee theory suggested by one of us.[4] This variant replaces the grand canonical ensemble by the pressure ensemble and deals only with quantities which can be operationally defined even for finite systems. The proof is based primarily on some of van Hove's theorems.[3]

[1] C. N. Yang and T. D. Lee, Phys. Rev. **87**, 404 (1952).
[2] C. N. Yang, "Special problems of statistical mechanics I" (mimeographed lecture notes, Seattle, 1952), p. 31.
[3] L. van Hove, Physica **15**, 951 (1949).
[4] A. J. F. Siegert, Phys. Rev. **90**, 243 (1954).

**VA8. An Exact New Reformulation of the Many Body Problem.** J. K. PERCUS, *New York University Institute of Mathematical Sciences,* AND G. J. YEVICK, *Stevens Institute of Technology.*—In previous work,* we have introduced collective coordinates $(\Sigma\exp(ikx_i))$ for the purpose of transforming the $N$-body problem into that of a set of linear harmonic oscillators. The justification for this method is that the resulting oscillators appear to be dynamically independent. Up to now, the error inherent in the independent-oscillator picture eluded us. We here present the exact reformulation of the Lagrangian in terms of collective coordinates, utilizing for this purpose a set of very simple identities. The general procedure is first illustrated with the external potential terms in the Lagrangian, in which the concept of dynamical fourier coefficient is first introduced. The same procedure is applied to the internal potential terms, and now we obtain twofold dynamical fourier coefficients, the most significant terms being the "diagonal" coefficients which can be expressed by the two-particle correlation function of the system. The two-particle correlation function is seen to play an important role in the dynamical theory, as indicated in previous work on the superfluid, Helium II. Finally, a similar technique is used to recast the kinetic-energy term.

* Detailed papers have been submitted to Phys. Rev.

**VA9. The Exact Classical and Quantum Mechanical Equations of Motion for $N$ Particles Using Collective Coordinates.** G. J. YEVICK, *Stevens Institute of Technology,* AND J. K. PERCUS, *New York University Institute of Mathematical Sciences.*—First, the exact quantum-mechanical Schrodinger

equation in collective coordinates can be obtained in a simple, nonforced manner by the methods of the preceding abstract. The only change is in the quantum-mechanical kinetic-energy operator, which is handled in a general fashion. Specific quantum-mechanical terms appear which can be suitably eliminated. The statistics are made manifest by the special form of the boundary conditions in $q$-space. Next, the exact classical equations of motion for the collective coordinates are presented. These equations represent a set of $N$-coupled harmonic oscillators which correspond in various approximations to the equations considered in previous work. An interesting feature in the above is that only $2N$ collective coordinates are required in the exact theory as opposed to the infinite number which one would expect. These higher dependent $q_k$'s (which we can express in terms of the $N$ independent coordinates) play a paramount role in the understanding of finer physical details in the general dynamical theory of $N$-particles. The solution of the classical equations of motion has been initiated by means of the method of variation of parameters, which allows one to make a detailed study of such problems as the transition from order to chaos.

**VA10. Particle Motion in Nonrelativistic Quantum Theory.** RALPH SCHILLER, *Stevens Institute of Technology.*—In the nonrelativistic quantum theory of a spinning electron it is found that the usual transition to classical mechanics cannot be made via the route of ray optics. The velocity of the particle can no longer be written as the gradient of a scalar function so that the Hamilton-Jacobi theory must be generalized for a transition to classical mechanics to be effected. In this generalization the velocity field for the particle must be written $v=\nabla s+\xi\nabla\eta$,[1] which is the Clebsch decomposition for an arbitrary vector field. We show that for a nonrelativistic particle of arbitrary spin whose motion is determined by a Schrodinger-type equation, the velocity field always has the Clebsch form, $v=\nabla\varphi+\cos\theta\nabla\chi$ where $\theta$, $\chi$, and $\varphi$ are the Euler angles of rotation. If the field describes a particle that is capable of distortion in addition to rotation (the particle might have a varying quadrupole moment) then the velocity field depends on the parameters of distortion as well as the parameters of rotation.

[1] Bohm, Schiller, and Tiomno, Nuovo cimento (to be published).

**VA11. Applications of Topology to General Relativity.** C. W. MISNER,* *Princeton University.*—We look upon the set of homogeneous differential equations consisting of the Einstein field equations together with Maxwell's equations and the Dirac equation for a neutrino in general relativistic form as the statement of an as yet unquantized unified field theory. The topological content of these equations implied by the theorems of Hodge and de Rham is pointed out. A relationship between critical points of the metric (where $(-g)^{\frac{1}{2}}=0$) and annihilation of the "particles" of this theory is given. The existence of nontrivial solutions of the field equations is not established.

* Proctor Fellow.

**VA12. Flat Picture of Curved Space.** F. J. BELINFANTE, *Purdue University.*—Gupta's quantization of Einstein's gravitational field suggests simplifying nature's laws in systems $S$ "flat" at infinity and satisfying De Donder's coordinate condition, by introducing an auxiliary tensor $\gamma_{\mu\nu}=\delta_{\mu\nu}(1-2\delta_{\mu 0})$ in one such system $S_0(ct,x,y,z)$, thus singling out a Lorentz group. Not being uniquely determined, $\gamma_{\mu\nu}$ is subject to "gauge transformations" (=variety of choice). Therefore, Rosen's geometrical interpretation of $\gamma_{\mu\nu}$ (Phys. Rev., 1940) is unjustified, and the question of "gauge invariance" of Gupta's quantization deserves attention. From $S_0$ conventionally obtain a polar coordinate system $S_r(ct,r,\theta,\varphi)$, and find the static spherical empty-space solution of Einstein's equations for the metric $g_{\mu\nu}$ around the origin in $S_r$. Comparison with Schwarzschild's solution shows $r=\rho-m$, if $\rho=$Schwarzschild's radical variable. Radial distances $R=\int(g_{\rho\rho})^{\frac{1}{2}}d\rho$ for points with $\rho<2m$ are imaginary; thence, points $r<m$ not corresponding to real points in space should be omitted from the quantum-field theoretically useful flat picture of curved space $S_r$ on scale $(\gamma_{\mu\nu}dx^\mu dx^\nu)^{\frac{1}{2}}$: $(g_{\mu\nu}dx^\mu dx^\nu)^{\frac{1}{2}}$. In spacetime this provides tubelike holes as "worldtubes" of particles. ("Swiss-cheese model"). Fields surrounding actual particles may prevent such holes in the "flat" picture of space.

**VA13. Defining Invariants of Metric Spaces.** ARTHUR KOMAR, *Princeton University.*—The importance of the problem of characterizing the metric spaces of General Relativity by sets of invariants, as a more precise formulation of Mach's Principle is presented. It is found that two $n$-dimensional spaces are locally applicable if the equating of the sets of all fundamental scalars of orders up to $n+2$ in derivatives of the metric, of both spaces, form a consistent set of equations for the solution of the coordinate transformations which are to take one from one metric to the other. In this sense these scalars form a (in general highly overdetermined) set of invariants which define the space.

**VA14. A Formulation of Relativity.** HUSEYIN YILMAZ, *Stevens Institute of Technology.*—The two principles of special relativity; namely, the covariancy of natural laws and the invariancy of the velocity of light are derived from a common principle called the principle of superposition. It is shown that the quantities which satisfy the principle are scalars, vectors, tensors, and spinors. Covariant and the contravariant components arise from the fact that for any solution of the principle there is another solution which is dual to the first. Therefore, for any description of nature there is a dual description. The metric character of physics then follows from the requirement that the two descriptions must lead to the same physical conclusions. Other interesting aspects are discussed.

**VA15. A Classical Microphysics.** GERTRUDE T. SCHWARZMANN.—Interpretation of wave and corpuscle state as alternate, equivalent states of the entities of light and matter, of particle waves as alternating currents with a direct-current component, of their velocities those of the associated particles, of spin motion as full-fledged motion is the foundation to a classical microphysics. The composite character of revolution, sense of revolution always equal to sense of spin, allows of differentiating earthial from mercurial motion. For earthial motion the spinning corpuscle ring alters; for mercurial motion it maintains its orientation relative to its radius vector, so that its spin component is transformed into a second revolutional component. Assuming that the cutting of magnetic lines of force by the spinning corpuscle ring is prerequisite to the transition corpuscle into wave, the electron, mercurially spiraling towards the nucleus, cannot emit radiation, interpreted as wave phenomenon. Interpolated between mercurial spirals and earthial stationary orbits are the earthial transition orbits wherein the electron, on transition from an $m$th into an $n$th orbit spinning $2n$ times per revolution, is transformed into the associated electron wave which decomposes at the perihelion into the corresponding light wave of frequency $R.c.(m^2-n^2)/n^2\cdot m^2$ and electron wave of frequency $v_n^2\cdot m_2/h$, whereupon both component waves revolve around the nucleus.

SATURDAY AFTERNOON AT 1:30

Burgundy Room

(M. A. TUVE presiding)

## *Apparatus of Nuclear Physics, II*

**W1. An Occluded-Gas Ion Source.*** LAWRENCE RUBY AND JAMES D. GOW, *University of California, Berkeley.*—An occluded-gas-pulsed ion source has been developed which embodies a method of obtaining large quantities of ions and electrons from hydrogenated titanium. The plasma is released when a spark is initiated on the surface of the metal. To achieve this in vacuum, a capacitor or pulse line is discharged across a sandwich of titanium separated by a thin insulator. A stack of such metal-insulator elements is used to average out individual variations in the sparks. A typical stack is $\frac{1}{4}$ in. diameter by 1 in. long. With axial geometry and a 3/32-in. source opening, 10 ma at 10 KV has been extracted with an aperture electrode and 250 ma, correspondingly, with a grid electrode. With radial geometry, ions have been extracted using a slot electrode. Pulse lengths have ranged from 10 $\mu$sec to 1 msec at rates as high as 5 pps. $H^+$ dominates $H_3^+$ by a factor of 3 in the mass-emission spectrum. The composition of the insulators influences the spectrum. Advantages of the source are its high output, compact size, high ratio of atomic to molecular ions, independence of a magnetic field, and gas economy.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

**W2. Triggering a Fast Two-Crystal Compton Scintillation Spectrometer with Iodine-Escape X-Rays from the NaI(Tl) Primary Crystal.** P. R. HOWLAND AND N. E. SCOFIELD, *U. S. Naval Radiological Defense Laboratory.*—Using the 133.5 kev[1] line in $Ce^{144}-Pr^{144}$ a peak has been observed in the pulse-height spectrum of a Compton scintillation spectrometer which corresponds to the usual escape peak observed in single-crystal spectrometers but which differs in the mechanism of observation in that the escape peak is triggered by escape x-rays which leave the primary crystal and are incident on the secondary crystal. This escape peak for the 133.5-kev line has an energy of 98±3 kev. By discriminating against the secondary crystal pulses up to and including weighted average energy of the escaping iodine $K$ x-rays, it is possible to make the escape peak disappear. This method gives a possible means of distinguishing photoelectric processes from Compton processes at incident energies up to about 200 kev.

[1] Cork, Brice, and Schmid, Phys. Rev. **96**, 1295 (1954).

**W3. Monte Carlo Calculation of the Response of NaI(Tl) Scintillation Spectrometers.** MARTIN J. BERGER AND JOHN A. DOGGETT, *NBS.*—Measurements of $\gamma$ rays with NaI(Tl) crystals yield pulse-height distributions related to the true energy spectrum by an integral equation whose kernel (response function) is the probability that an incident photon of energy $E$ will give rise to a pulse of size $E'$. We have calculated this function for photons with energies from 0.279 to 4.45 Mev, incident on cylindrical crystals ranging from $\frac{1}{2}$ in. (diameter)×$\frac{1}{2}$ in. (length) to 5 in.×9 in. Most of the calculations pertain to collimated sources, some to incident broad beams and point isotropic sources. Compton scattering and absorption were treated by the Monte Carlo method. A total of 50 000 random walks were computed and analyzed on the NBS automatic computer. Analytical corrections were made for the escape of annihilation radiation and bremsstrahlung. The shape of the response function is determined in first approximation by a characteristic parameter $p$ = (area under photopeak)/(area under entire pulse-height spectrum), a smooth function of (crystal length×diameter)$^{\frac{1}{2}}$. For small crystals, our values of $p$ are in good agreement with those obtained by Maeder *et al.*[1] by an approximate analytical calculation.

[1] Maeder, Müller, and Wintersteiger, Helv. Phys. Acta, **27**, 3 (1954).

**W4. Oxygen Quenching and Wavelength Shifters in Liquid Scintillators.** C. A. ZIEGLER, H. H. SELIGER, AND L. JAFFE, *NBS.*—We have investigated the effects of oxygen quenching and of the addition of a wavelength shifter under more well-defined conditions of oxygen removal than reported previously.[1,2] Oxygen-free solutions prepared and flame-sealed under vacuum were compared with oxygen-saturated solutions using the $\gamma$ rays from $Cs^{137}-Ba^{137}$ and a Dumont 6292 PMT in a reproducible geometry. The integral of the pulse-height distribution curve was assumed to be proportional to the light output. We have found that the major contribution of the wavelength shifter $\alpha$ naphthylphenyloxazole is to compete with dissolved oxygen for the energy in the solution, the former emitting light and the latter de-exciting by other processes. The 23 percent gain in sensitivity to be expected on the basis of the shift in the emission spectrum is almost completely compensated for by the approximately 83 percent efficiency for the energy transfer from solute to shifter. Data with $p$-terphenyl, 2,5-diphenyloxazole and $\alpha$ napththylphenyloxazole in zylene will be presented.

[1] Pringle, Black, Funt, and Sobering, Phys. Rev. **92**, 1582 (1953).
[2] J. R. Arnold, Science **119**, 155 (1954).

**W5. Response of a Sodium-Iodide Spectrometer to High-Energy Electrons.*** H. W. KOCH, J. M. WYCKOFF, AND B. PETREE, *NBS.*—Monoenergetic electrons from a 50-Mev betatron operated between 1 and 20 Mev were used to study the performance of a 5 in. by 4 in. and a 5 in. by 9 in. NaI(Tl) total-absorption spectrometer.[1] The pulse-height distributions produced by bombardment of the central axis of the large crystals show very peaked distributions with small tails. The energy resolution reaches its optimum value at 10 Mev where the total width at half maximum is 4 percent, whereas the comparable resolution for 10-Mev x-rays would be 9 percent.[1] This added width to the x-ray pulse-height distribution results largely from the escape of one annihilation photon from the crystal. Synthesis of the x-ray distributions from the electron distributions and the linearity of spectrometer response to electron energy will be discussed.

* Supported in part by the U. S. Office of Scientific Research of the Air Research and Development Command.
[1] R. S. Foote and H. W. Koch, Rev. Sci. Instr. **25**, 746 (1954).

**W6. A Fast Multichannel Coincidence Circuit.*** T. H. BRAID AND R. W. DETENBECK,† *Princeton University.*—For delayed coincidence and time of flight experiments, it is advantageous to measure the time distribution of coincidences in a multichannel device. The condenser discharge principle used in the present circuit is due to Rossi and Nereson.[1] The first signal cuts off a diode, allowing a condenser to discharge slowly through a resistance. The delayed signal stops the discharge. The amplitude of the pulse from the $CR$ circuit is proportional to the delay time $T$ if $CR \gg T$. These pulses are fed to a twenty-channel pulse-height analyzer, gated by a slow conventional coincidence circuit so that single pulses are not

recorded. We have used the circuit so adjusted as to be linear up to 0.1 microsecond delay and have obtained a resolving time $2\tau = 3.10^{-9}$ second. This was measured with $Na^{22}$ annihilation quanta (one side artificially delayed) and terphenyl crystals as detectors.

* Supported by the U. S. Atomic Energy Commission and the Higgins Fund.
† National Science Foundation Predoctoral Fellow.
‡ Rossi and Nereson, Rev. Sci. Instr. 17, 65 (1946).

**W7. A Precision Monitor for Electron Beams.*** G. W. TAUTFEST AND K. L. BROWN, *Stanford University*.—Two Faraday-cup electron beam monitors have been developed which are capable of measuring the absolute integrated beam current of the Stanford linear accelerators to an accuracy of better than $\pm\frac{1}{2}$ of one percent and $\pm 2$ percent, respectively. The combined energy range of these integrators is from 1 Mev to better than 300 Mev. With the techniques employed, it is evident that with only minor modifications in size, the useful range of such beam monitors can be extended to energies beyond 1 Bev. Design principles and construction details will be discussed. Such monitors have proved to be especially valuable in conjunction with the Stanford linear accelerators where large peak currents of small cross-sectional area are frequently used.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.

**W8. A New Multichannel Recording Time-Delay Analyzer.*** P. G. KOONTZ, C. W. JOHNSTONE, G. R. KEEPIN, JR., AND J. D. GALLAGHER, *Los Alamos Scientific Laboratory*.—A new time-delay analyzer encompassing a wide, flexible time base will be described. The system includes three basic units: (1) a four-decade gated scaler with pulsed reset; (2) a crystal controlled interval timer; and (3) a coincidence readout circuit which duplicates the instantaneous reading of the gated scaler at intervals established by pulses from the timer unit. Time channels of 0.001-, 0.01-, 0.1-, 1-, and 10-sec width are provided; these may be combined either in progressive sequence starting with a preselected channel width, or used individually on continuous operation at a single channel width. Provision is made for either photographic recording or electrical print-out on electrosensitive paper. Data obtained with the new analyzer agree with a conventional ten-channel time-delay analyzer over the limited range of the latter. A simple procedure is available for checking correct operation of the system. The development of this analyzer was prompted by the need for such an instrument to study the complex decay of delayed neutron emitters produced in the fission process. However, it was purposely developed as a versatile system capable of handling a wide range of problems requiring time-delay analysis.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**W9. A New Type of Lens for Charged Particles.*** NATHANIEL P. CARLETON, *Harvard University* (introduced by O. Oldenberg).—An electrostatic lends for charged particles can be made by producing a potential which varies continuously with the distance along a cylindrical surface coaxial with the beam of particles. In particular, when the potential varies along the cylinder as the square of the distance from some original plane, then the equations of motion for a charged particle in the cylinder are easily solvable and the particle trajectories found analytically. From the trajectories one sees that this potential configuration acts as a positive or negative lens which has no aberrations when both object and image are in the field and other special conditions are also met. The aberrations of this lens when it is used with the object and image outside the field have not been calculated, but use of the lens to focus low-energy protons indicates that aberrations may be smaller than those of conventional focusing fields. The lens can be perfectly realized by depositing a conducting film of variable thickness inside a glass cylinder and passing a current through it. In tests, the theory was realized approximately by a succession of closely spaced rings, maintained at the proper potentials.

* This work was partially supported by the Air Force Cambridge Research Center.

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## SATURDAY AFTERNOON AT 1:30

Main Ballroom

(M. DEUTSCH presiding)

### *Invited Paper*

**X1. The Transuranium Elements.** A. GHIORSO, *University of California, Berkeley*. (40 min.)

### *Various Topics in Nuclear Physics*

**X2. An Attempt to Detect Neutrinos by the Reaction $Cl^{37}(\bar{\nu},e^-)A^{37}$.*** RAYMOND DAVIS, JR., *Brookhaven National Laboratory*.—Large volumes of carbon tetrachloride have been irradiated adjacent to the Brookhaven reactor in an effort to observe the reaction $Cl^{37}(\bar{\nu},e^-)A^{37}$ induced by fission-product neutrinos. The experiments have demonstrated that radioactive $A^{37}$ can be removed from 1000-gallon quantities of carbon tetrachloride by sweeping with helium gas. The background amounts of $A^{37}$ induced in carbon tetrachloride by the nucleonic component of cosmic radiation, and fast neutrons has been measured. An upper limit to the cross section was set of $2\times10^{-46}$ cm² per atom. The background effects prevented observing lower values of the cross section. The possibility of observing the theoretically calculated cross section of $4\times10^{-46}$ cm² per atom will be discussed.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

**X3. Annihilation Radiation from Positrons Stopping in Superconducting Lead.** S. M. SHAFROTH AND J. A. MARCUS, *Northwestern University*.—Coincident two-quantum annihilation radiation from positrons stopping in lead at 4.2°K was observed alternately in a magnetic field of 750 gauss and with no field. Thus the lead was alternately in its normal state and in its superconducting state. The lead was shown to be superconducting in a separate experiment. In a manner similar to Pond's[1] method we look for differences in the two-quantum

coincidence rate which would indicate an enhancement of the three quantum radiation when the lead was superconducting as was first suggested by Dresden.[2] The source was $Na^{22}$ surrounded by lead disks 0.010 in. thick. It was immersed in liquid helium, and then placed between the poles of an electromagnet. Two scinillation counters were connected in coincidence to a circuit with a resolving time of $2\times10^{-8}$ sec. The counters were placed 180° apart with a source half way between them. Solid angles of $10^{-2}$ and $3\times10^{-4}$ steradian were employed. No difference in counting rate from superconducting to nonsuperconducting was observed to within a statistical accuracy of 0.10 percent.

[1] T. A. Pond, Phys. Rev. 93, 478 (1954).
[2] M. Dresden, Phys. Rev. 93, 1413 (1954).

**X4. Temperature Effects in the 3-Quantum Annihilation of Positrons.*** R. T. WAGNER AND F. L. HEREFORD, *University of Virginia.*—The ratio of three-quantum to two-quantum annihilation of positrons in ice and zinc has been investigated in the 4°–300°K temperature range. The positron source ($Na^{22}$) was prepared by dissolving sodium chloride in distilled water in a 5-ml flask which was then placed at the bottom of a Dewar. The ratio of three-photon to two-photon annihilations at various fixed low temperatures was then measured using a triple coincidence circuit. An approximately linear decrease in this ratio is noted with decreasing temperature in the ice similar to results in teflon.[1] Using the same apparatus, this ratio was measured by positron annihilations in zinc in which the positron emitter ($Zn^{65}$) was the absorber. Here no temperature effect is observed. The correlation of these results with the data[2] on positron lifetimes will be discussed.

* Supported by Office of Ordnance Research.
[1] R. L. Graham and A. T. Stewart, Can. J. Phys. 32, 678 (1954).
[2] R. E. Bell and R. L. Graham, Phys. Rev. 90, 644 (1953).

**X5. Angular Correlation of Two-Quantum Annihilation in Condensed Materials.*** L. A. PAGE, M. HEINBERG, O. J. WALLACE, AND T. W. TROUT, *University of Pittsburgh.*—Positron annihilation is being studied in apparatus similar to that of DeBenedetti *et al.*[1] with the addition of slits to shield the gamma detectors from the 5-mC $Na^{22}$ source. A narrow component has been isolated in fused quartz, comprising about 20 percent of the total annihilations, with width-at-half-maximum no greater than $3\times10^{-3}$ radian. Other materials having the long lifetime component as listed by Bell and Graham,[2] exhibit an angular distribution similar to fused quartz, while materials listed as having no long lifetime have, by comparison, a structureless distribution. To date, from data at room temperature, the former group is fused quartz, teflon, polystyrene, polyethylene, paraffin, and lucite; the latter group is crystalline quartz, aluminum, magnesium, copper, and graphite. Preliminary magnetic quenching experiments[3] increase the amount of narrow component by applying a strong field to fused quartz and teflon, but give no observable change for crystalline quartz. Quantitative comparison of this effect with expectation based on measured[2] lifetimes and percentage long-life component will be made.

* Work done in Sarah Mellon Scaife Radiation Laboratory, supported by the Office of Ordance Research.
[1] DeBenedetti, Cowan, Konnecker, and Primakoff, Phys. Rev. 77, 205 (1950).
[2] R. E. Bell and R. L. Graham, Phys. Rev. 90, 644 (1953).
[3] Compare M. Deutsch and E. Dulit, Phys. Rev. 84, 601 (1951).

**X6. Internal Pair Creation in Negatron Decay.*** J. S. GREENBERG AND M. DEUTSCH, *M.I.T.*—Using a fairly thin and uniform source of $P^{32}$ (about 25 millicuries in one milligram), it was found that the negatron decay of $P^{32}$ is accompanied by the emission of electron positron pairs with an abundance of $0.9\pm0.6\times10^{-9}$ per beta decay. This corresponded in the experiment to an average counting rate of 3.5 positrons per hour from the source. The fractional contribution to this number by secondary effects in the source material could not be determined due to uncertainties in the source thickness and composition. However, the results indicate that the ratio of positrons emitted to negatron decays is probably not greater than $1.5\times10^{-9}$, which is of the order of magnitude predicted by the theory of Arley and Möller.[1] The method of detection used was to employ a magnetic field to focus the positrons emitted by the source onto a beryllium catcher placed longitudinally along the magnetic field. The annihilation of the positrons in the beryllium catcher was then detected by means of the characteristic 180° coincidences of the 0.51-Mev gamma rays. Appropriate baffles and shielding were used to prevent detection of positrons that were not produced in the source.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Arley and Möller, Det. Kgl. Danske Vid. Selskab. 15, 9 (1938).

**X7. $Z$-Dependence of Bremsstrahlung.*** K. L. BROWN, W. C. BARBER, A. I. BERMAN,† AND W. D. GEORGE, *Stanford University.*—The relative amounts of bremsstrahlung produced by the elements Cu, Ta, Pb, and U for incident electrons of energy 24 and 34 Mev were measured using the $Cu^{63}(\gamma,n)Cu^{62}$ reaction as the photon detector. This reaction has a cross section with an effective absorption energy of 17.5 Mev and a width at half maximum of 5 Mev so that photons were detected in a comparatively narrow energy band. The electron beam was monitored by a Faraday cup placed immediately behind the radiator and detector foils. Corrections were applied to account for ionization and radiation losses of the electrons and for pair production and Compton losses of the photons. The experimentally determined "thin-target" bremsstrahlung cross sections relative to copper were $5.681\pm0.13$, $6.959\pm0.16$, and $8.221\pm0.19$ per atom for Ta, Pb, and U, respectively, at 24 Mev; and $5.583\pm0.08$, $6.770\pm0.09$, and $8.172\pm0.12$ at 34 Mev. These results are from five to thirteen percent lower than the corresponding ratios calculated from the Bethe-Heitler theory (including screening and radiation produced in collision with atomic electrons). The results are consistent with a deviation from theory of $(1.44\pm0.1)\times10^{-3}Z^2$ percent.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now with Pratt-Whitney, Hartford, Connecticut.

**X8. Prediction of Auroral Gamma Rays.*** STIRLING A. COLGATE, *University of California, Livermore.*—The aurora has been explained by protons from the sun. The mean depth of atmospheric penetration of 110 km predicts a primary proton energy of 300 kev. A few aurora have been observed to penetrate to 70 km, implying 6-Mev protons. Störmer's calculations would limit such particles to magnetic latitudes much closer to the magnetic pole than the observed incidence, implying that the proton energy is greater than that derived from the range. If the incident proton energy is greater than 2.6 Mev (the lowest level of $N^{14}$) the $N^{14}$ $(p,p^1)$ $\alpha$ reaction should give rise to an observable gamma flux. The $N^{14}$ $(p,p^2)$ $\alpha$ cross section has been measured at 7.4 Mev. A measurement was made by the author of the gammas from 31-Mev protons stopping in air. The Mev gammas per proton stopping in air is approximately $10^{-6}E_p^3$, $3<E_p<30$ Mev. The incident proton flux divided by the solid angle to the observer can be estimated from the intensity of total light, or from the intensity of the $H_\alpha$ emission as $10^7/E_p$ protons/sec per ($cm^2$ solid angle) at the observer. For 3-Mev incident protons, this gives $10^2$ Mev $\gamma$'s/$cm^2$/sec above the earth's atmosphere and approximately $10^3$ Mev $\gamma$'s/$cm^2$/sec at 50 000 feet.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Fan and Meinel, Astrophys. J. 118, 205 (1953).
[2] Bennett and Hulburt, Phys. Rev. 95, 315 (1954).

**X9. Radiation Dosage from Thermonuclear Explosions.** M. S. STEINBERG, *Yale University* (introduced by A. Einstein).—It is of interest to demonstrate a method for estimating thermonuclear explosion radiation dosage using publicly available data from the Japanese ship, Fukuryu Maru. The world-average cumulative dose is given by $R_e = \dot{R}_s(t_0)D^{-1}(t_0)K_s^{-1}(t_0) \times \int D(t)K_e(t)dt$, where the dosage rate $\dot{R}(t)$ due to fallout is proportional to the gross decay factor $D(t)$ and to the surface density of fallen matter $K(t)$ in the effective area of exposure. It is assumed that the measured shipboard fallout was characteristic of the general fallout. Subscripts $e$ and $s$ refer to earth and ship respectively, and the integration extends over the genetically significant exposure time; $K_e(t)$ is assumed to increase linearly during fallout and thence to remain constant at $K_{e0}$ while $D(t)$ is assumed of the form $t^{-p}$. The rate of fallout is determined from Stokes' Law; $K_{e0}$ is obtained from the excavated matter estimate of Martin; $\dot{R}_s$ (16 days) has been measured by Nishiwaki; and $K_s$ (16 days) and $p$ are estimated from Kyoto University studies on the shipboard fallout. For the spring, 1954 explosions we find $R_e \sim 5$ roentgens, excluding effects of fallout ingestion.

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## SATURDAY AFTERNOON AT 1:30

## Exhibit Hall II

(E. K. PLYLER presiding)

## *Microwave and Band Spectra*

**XA1. Two Quantum Transitions in the Microwave Zeeman Spectrum of Atomic Oxygen.** V. W. HUGHES AND J. S. GEIGER, *Yale University*.—The three extra lines observed by Rawson and Beringer[1] in the microwave spectrum of ground state $^3P_2$ atomic oxygen have been identified as arising from two quantum transitions between Zeeman levels with the selection rule $\Delta M = \pm 2$. Each of the three lines is observed at the mean frequency of the two corresponding $\Delta M = \pm 1$ transitions to within the experimental accuracy of a few ppm. The line width of the two quantum transitions is approximately one half that of the normal transitions, and the line intensity varies more rapidly with rf power, both in agreement with the theory. One extra two quantum line is predicted for the $^3P_1$ Zeeman spectrum; however, this line would be weak and also would occur at the frequency of a line in the $^3P_2$ Zeeman spectrum. This line has not been observed. Multiple quantum transitions have been previously reported in the electric quadrupole radiofrequency spectrum of RbF and in the Zeeman spectrum of $O_2$ and K.[2] The theory of such transitions has been discussed.[3]

[1] Rawson and Beringer, Phys. Rev. **88**, 677 (1952).
[2] Hughes and Grabner, Phys. Rev. **79**, 314 (1950); **82**, 561 (1951); P. Kusch, Phys. Rev. **93**, 1022 (1954).
[3] Hughes and Grabner, Phys. Rev. **79**, 829 (1950); Preprint from H. Salwen.

**XA2. Microwave Spectrum of the Ozone Molecule.*** E. K. GORA, *Providence College*.—The frequencies and intensities of 191 absorption lines of ozone in the microwave domain between 0 and 11 $cm^{-1}$ have been calculated. All the lines have been taken into consideration from which a measurable contribution to microwave absorption is to be expected. This has made it necessary to extend the calculations to transitions between levels of rotational quantum numbers as high as $J = 50$. For the calculation of the transition frequencies standard methods have been employed, but for the calculation of the intensities a simplified computational procedure has been developed. The mathematical methods for the intensity calculations described by previous authors become very cumbersome for transitions between levels of high rotational quantum numbers, but the simplified computational procedure has made it comparatively easy to determine all the ozone line intensities. The sub-branch structure of the spectrum is described in detail.

* Supported by the U. S. Air Force through the Air Force Cambridge Research Center.

**XA3. Centrifugal Distortion Effects in Ozone.*** LOUIS PIERCE, *Harvard University*.—The microwave spectrum[1,2] of ozone has been reanalyzed to include the effect of centrifugal distortion. Using the energy expression given by Kivelson and Wilson,[3] it was possible to fit eighteen lines of the rotational spectrum to within a mean deviation of $\pm 1.5$ Mc. The rotational constants determined in this manner are $A = 106\,534.45$ Mc, $B = 13\,349.10$ Mc, $C = 11\,834.14$ Mc. The four distortion constants obtained in this analysis predicted vibrational frequencies which were of the right order of magnitude. The relation of these constants to the vibrational spectrum will be discussed in terms of the theory developed by Kivelson and Wilson.[4]

* Supported by the Office of Naval Research.
[1] R. H. Hughes, J. Chem. Phys. **21**, 959 (1953).
[2] Tzambarulo, Ghosh, Burrus, and Gordy, J. Chem. Phys. **21**, 851 (1953).
[3] D. Kivelson and E. B. Wilson, Jr., J. Chem. Phys. **20**, 1575 (1952).
[4] D. Kivelson and E. B. Wilson, Jr., J. Chem. Phys. **21**, 1229 (1953).

**XA4. Microwave Spectra of Indium Chloride and Bromide.*** A. H. BARRETT AND M. MANDEL, *Columbia University*.—The pure rotational spectra of indium monochloride and indium monobromide have been observed using a high-temperature spectrometer.[1] Internuclear distances and vibration-rotation interaction constants determined are

| Molecule | $r_e$(A) | $\alpha_e$(Mc/sec) |
|---|---|---|
| $In^{115}Cl^{35}$ | 2.4012 ±0.0001 | 15.34 ±0.15 |
| $In^{115}Br^{79}$ | 2.5408 ±0.0001 | 5.706 ±0.025 |
| $In^{115}Br^{81}$ | | 5.605 ±0.018 |

Since the nuclear spins of $In^{115}$, $Cl^{35,37}$, and $Br^{79,81}$ are 9/2, 3/2, and 3/2, respectively, the spectra are complicated by hyperfine structure resulting from the interaction of each electric quadrupole moment with the molecular field. The spectrum of $In^{115}Cl^{35}$ yielded values of $-655 \pm 6$ Mc for the $In^{115}$ coupling constant and $-24 \pm 2$ Mc for the $Cl^{35}$ coupling constant. The quadrupole structure was not sufficiently resolved to allow a determination of the coupling constants in $In^{115}Br$. Interpretation of the results in terms of ionic character and bond hybridization of these molecules will be discussed.

* Work supported jointly by the Signal Corps, the Office of Naval Research, and the Air Research and Development Command.
[1] Stitch, Honig, and Townes, Rev. Sci. Instr. **25**, 739 (1954).

**XA5. Theory of the Fine Structure of the Microwave Spectrum of $NO_2$.*** CHUN C. LIN† *Harvard University*.—The theory of hyperfine structure of $NO_2$ first proposed by McAfee[1] has been re-examined and revised to include the case where the spin-rotation interaction and the dipole-dipole coupling are of the same order of magnitude. This theory satisfactorily accounts for the frequency of the ten lines observed by Bird.[2] Some small deviations, however, do exist. The origin of these

discrepancies is not clear; they are probably due to second order effects of the magnetic interactions. The predicted intensities of the ten lines also agree with observation within the experimental accuracy. The magnetic coupling constants obtained from this investigation are rather bizarre and may furnish interesting information about the electronic structure of $NO_3$. The theory of the Zeeman effect is also being studied and compared with experiment.

* Supported in part by the Office of Naval Research.
† duPont Company Predoctoral Fellow.
[1] K. B. McAfee, Jr., Phys. Rev. **78**, 340(A) (1950); Phys. Rev. **82**, 971 (1951).
[2] G. R. Bird, Bull. Am. Phys. Soc. **30**, 21 (1955), abstract H6.

**XA6. Internal Motion in Methyl Amine.*** D. KIVELSON, *M.I.T.*, AND D. R. LIDE, JR., *N.B.S.*—The microwave spectrum[1,2] of methyl amine exhibits hindered internal rotation of the $NH_2$ group with respect to the $CH_3$ group, as well as inversion doubling arising from the fact that there are two equally likely orientations of one NH bond with respect to the other. An approximate theory has been worked out for these two internal motions and their mutual interaction. By a suitable choice of variable the kinetic energies can be completely separated; the potential energy can be reduced to a term accounting for inversion, a term accounting for hindered internal rotation, and an interaction term. If the latter is neglected the two internal motions can be treated independently except for their interrelated dependence upon the periodic boundary conditions. The interaction term can be treated by a Van Vleck transformation. This theory is applied to methyl amine.

* This work was supported in part by the Signal Corps; the Office of Scientific Research, Air Research and Development Command; and the Office of Naval Research.
[1] D. R. Lide, Jr., J. Chem. Phys. **20**, 1812 (1952); **21**, 571 (1953).
[2] Shimoda, Nishikawa, and Itah, J. Chem. Phys. **22**, 1456 (1954); J. Phys. Soc. Japan **9**, 974 (1954).

**XA7. Molecular-Beam Microwave-Absorption Spectroscope.*** M. PETER AND M. W. P. STRANDBERG, *M.I.T.*—A microwave absorption spectroscope has been developed, whose absorption-line half-power—half-width is determined by the average time that the molecules under observation are exposed to the microwave field. This is an improvement over the similar previous device by Strandberg and Dreicer,[1] in which the Stark modulation frequency limited the resolution. In both devices the Doppler broadening, which limits the resolution of the usual microwave spectroscopes, is eliminated. An improvement by a factor of twelve is now obtained over such usual systems, and a half-power—half-width of 3 kc has been observed. To use such resolution it has been necessary to develop a stabilization circuit which maintains the phase of a *K*-band klystron to within a few degrees of the phase of some harmonic of a very stable quartz oscillator. The resolution of the present system is therefore limited only by geometry and may thereby be improved by use of longer average observation times, i.e., use of longer molecular beams.

* This work was supported in part by the Signal Corps; the Office of Scientific Research, Air Research and Development Command; and the Office of Naval Research.
[1] M. W. P. Strandberg and H. Dreicer, Phys. Rev. **94**, 1393 (1954).

**XA8. Excited Torsional States in Asymmetric Hindered Rotors.*** P. R. SWAN AND M. W. P. STRANDBERG, *M.I.T.*—The $J=0\rightarrow1$ transition of methyl alcohol is being investigated. Because of internal torsion in this type of molecule the transition is split into a series of doublets, each doublet corresponding to a particular internal torsion state. A preliminary model used was that of a rigid symmetric top attached at an arbitrary angle to a rigid asymmetric frame and allowed to rotate about its symmetry axis under the influence of a threefold cosine potential barrier. The resulting Hamiltonian was found to be incapable of predicting the torsional splitting when applied to the methyl-alcohol molecule. A semiempirical combination of Kivelson's[1] formula for the corresponding transition in a symmetric hindered rotor with matrix elements from this methyl-alcohol Hamiltonian was found to give a close fit to the observed spectrum. An additional feature of the methyl-alcohol spectrum is the large fourth-order Stark effect of one of the lines of the $J=0\rightarrow1$ series. The Hamiltonian necessary to describe these rotation-torsion interaction effects will be discussed.

* This work was supported in part by the Signal Corps; the Office of Scientific Research, Air Research and Development Command; and the Office of Naval Research.
[1] D. Kivelson, J. Chem. Phys. **22**, 1733 (1954).

**XA9. Electronic Contribution to Effective Nuclear Masses in Molecules.*** M. W. P. STRANDBERG, *M.I.T.*—The problem of the interaction of molecular rotational and electronic states has been extensively investigated in the past.[1-5] Quite briefly stated, it has been demonstrated that the molecular electrons contribute to the molecular moment of inertia tensor an amount which is directly and simply related to the molecular magnetic moment tensor. Examples of this correction have been made with the experimental results on several molecules, and the measured corrections to the principal moments of inertia arising from the molecular electrons have been discussed. The authors of a recent paper[6] reporting the deuterium-tritium mass ratio evaluated from microwave measurements attempted a discussion of this correction without apparently realizing that it is a matter which may be reduced to measurement. The electronic correction to spectroscopic mass ratio measurements will be discussed in terms of past work.

* This work was supported in part by the Signal Corps; the Office of Scientific Research, Air Research and Development Command; and the Office of Naval Research.
[1] H. B. G. Casimir, *Rotation of a Rigid Body in Quantum Mechanics* (J. B. Wolters', The Hague, 1931), Vol. 3.
[2] Gokhale, Johnson, and Strandberg, Phys. Rev. **83**, 881 (1951).
[3] H. R. Johnson and M. W. P. Strandberg, J. Chem. Phys. **20**, 687 (1952).
[4] B. F. Burke and M. W. P. Strandberg, Phys. Rev. **90**, 303 (1953).
[5] M. W. P. Strandberg, *Microwave Spectroscopy* (Methuen and Company, Ltd., London, 1954), Chap. VII.
[6] B. Rosenblum and A. H. Nethercot, Jr., Phys. Rev. **97**, 84 (1955).

**XA10. "Average" Internuclear Separations Arising in the Study of Molecular Band-Systems.*** R. W. NICHOLLS AND W. R. JARMAIN, *University of Western Ontario.*—The concept of an "average" internuclear separation or "$r$-centroid" $\rho_{v'v''}$ associated with the radiation of the $(v'\rightarrow v'')$ molecular band will be discussed. Methods of computation of arrays of $\rho_{v'v''}$ will be described. The properties of the $r$-centroid, and its application to the interpretation of band intensities will be reviewed.

* This research is assisted by the Air Force Cambridge Research Center.

**XA11. The Vibrational Spectrum of Tetrabromoethylene.*** D. E. MANN, JANET HAWKINS MEAL,† AND EARLE K. PLYLER, *National Bureau of Standards.*—The infrared spectrum of $C_2Br_4$ has been observed and measured in the range from 3 to 100 microns. These data, together with the older Roman spectra and a new force constant analysis, have enabled an essentially complete and satisfactory vibrational assignment to be achieved for the first time. In particular, the values of the angular fundamentals in the $b_{1u}$, $b_{2u}$, and $b_{3u}$ species have been established. The vibrational assignments for $C_2F_4$, $C_2Cl_4$, and $C_2Br_4$ are now fully concordant.

* This work was supported in part by the Office of Naval Research.
† National Research Council—National Bureau of Standards Postdoctoral Research Associate.

## *Invited Paper*

**XA12. Temperature-Measurement from Molecular Band Spectra (Nonequilibrium).** H. P. BROIDA, *National Bureau of Standards.* (30 min.)

SATURDAY AFTERNOON AT 1:30

NBS, East Building

(L. R. MAXWELL presiding)

## *Cryogenics*

**Y1. Intradomain Magnetic Saturation for Iron.** WARREN E. HENRY, *U. S. Naval Research Laboratory.*—Studies have been made of the magnetization of polycrystalline, 99.9 percent iron (Westinghouse) as a function of magnetic field for temperatures between 1.5°K and 300°K, in magnetic fields up to 60 000 gauss. For a given temperature, the magnetization rises with nearly constant slope with field until a certain field (about 8000 gauss for a sphere) is reached, which depends on the shape of the sample. The slope then goes quickly to zero and remains zero for fields up to 60 000 gauss. In the helium range (1.5°K−4.2°K), the saturation magnetization remains constant to within experimental error (0.2 percent). No appreciable remanence is observed in zero field. A ballistic, moving sample method[1] for measuring the magnetization was used. Analysis of the data is made in terms of departures from the quantum mechanical "$T^{\frac{3}{2}}$ Bloch law" (applicable over part of the range) and from the Weiss molecular field relation; empirical relations are put forth to correlate the data. Comparison is made between our data and previous work[2] done in more limited ranges of temperature and magnetic field.

[1] W. E. Henry, Phys. Rev. **88**, 559 (1952).
[2] M. Fallot, Ann. phys. **10**, 291 (1938).

**Y2. Thermodynamic Properties of Chrome Alum.*** L. D. JENNINGS AND MELVIN A. HERLIN,† *M.I.T.*—A new method was applied to the measurement of the thermodynamic properties of potassium chromium alum in the region of temperatures reached by adiabatic demagnetization. The method requires the measurement of adiabatic magnetization curves which approach an asymptotic value at large fields characteristic of the analogous ideal paramagnetic gas at the same entropy. The entropy of the actual salt is then given as that of the ideal salt which has the same large field magnetization. The temperature of the salt is given by a method, previously described,[1] which makes use of the deviation of the behavior of the actual salt from that of the ideal. Each adiabat is identified by $T^*$, the magnetic temperature at that entropy. We find good agreement with other workers for $T(T^*)$, but less satisfactory agreement for $S(T^*)$ in the region $T^*=0.1$ to $T^*=0.2$. This discrepancy is attributed to a failure of the usual computation of entropy near 1°K, to our need to extrapolate our results at high magnetic fields, or to an actual difference among samples.

* This work was supported in part by the Signal Corps; the Office of Scientific Research, Air Research and Development Command; and the Office of Naval Research.
† Now at Lincoln Laboratory, M.I.T.
[1] M. A. Herlin, Proc. Intern. Conf. Low Temp. Physics (Oxford, 1951), p. 144.

**Y3. An Ultra-Low-Level Voltage Detector Using Bismuth and Superconductors.** JULIUS BABISKIN, *Naval Research Laboratory.*—A direct-current or low-frequency amplifier which should be capable of detecting $10^{-12}$ volt in low-impedance circuits at low temperatures is under development. A single layer of bismuth wire is wound between two oppositely-wound layers (~0.1 microhenry) of superconducting lead wire. A superconducting lead shield eliminates stray magnetic fields. Current changes in the superconducting winding caused changes in the concentrated magnetic field over the bismuth activating its magnetoresistance. To eliminate bismuth calibration problems, the magnetoresistance minimum was chosen at a sacrifice in sensitivity as the balance point affording an absolute null point independent of the cyclical reproducibility, temperature, and thermal emf's of bismuth. For preliminary measurements on a prototype detector, the smallest detectable current change was $10^{-8}$ amp at the magnetoresistance minimum. Obvious design improvements should increase the detection limit considerably. Compared with a superconducting galvanometer,[1] the detector is simple, rugged, compact, and independent of vibration. This detector allows impedance matching between low-impedance voltage sources (e.g. temperature or magnetic field sensitive) in the superconducting circuit and measuring instruments at room temperature in the bismuth circuit.

[1] A. B. Pippard and C. T. Pullan, Proc. Cambridge Phil. Soc. **48**, 188 (1952).

**Y4. On the Superconductivity of Hafnium.** R. A. HEIN, *Naval Research Laboratory, and The Catholic University of America.*—The magnetic susceptibility and the electrical resistance of a hafnium rod[1] have been observed between 0.06°K and 4.22°K. The susceptibility measurements failed to reveal any evidence of superconductivity as previously reported.[2,3] The electrical resistance, which was constant in the liquid-helium range, started to decrease at 0.20±0.02°K and was still falling at the lowest temperature attained [$(R0.06°K/R0.20°K)=0.6$]. Since this effect was sensitive to small magnetic fields, a quasi-critical field curve was obtained. Susceptibility measurements made subsequent to a high-vacuum anneal again failed to indicate any superconductivity; however, the resistance of the annealed specimen did show an abrupt decrease at 0.15±0.03°K. This is in disagreement with the results of other workers.[3] The sensitivity of the magnetic measurements was such that if 10 percent of the hafnium had gone superconducting it would have been readily detectable.

[1] Supplied by the Materials Section, Wright Air Development Center, Dayton, Ohio, and had a stated purity of 98.92 percent.
[2] N. Kurti and F. Simon, Proc. Roy. Soc. (London), **A151**, 610 (1935).
[3] T. S. Smith and J. G. Daunt, Phys. Rev. **88**, 1172 (1952).

**Y5. Superconductivity of Tin Whiskers.*** O. S. LUTES, *NBS and University of Maryland,* AND E. MAXWELL,† *NBS.*—The superconducting resistance transitions of several tin whiskers[1] have been observed in the liquid-helium temperature range. The results are compared with those for larger wires and significant differences are found. In particular the transitions in a transverse magnetic field are discontinuous at temperatures substantially lower than the zero-field transition temperature. This result differs from that for larger wires,[2] which show intermediate resistance at these temperatures.

* This research was supported by the Office of Scientific Research of the Air Research and Development Command.
† Permanent address: Lincoln Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.
[1] Compton, Mendizza, and Arnold, Corrosion **7**, 327 (1951).
[2] E. R. Andrew, Proc. Roy. Soc. (London) **A194**, 80 (1948).

**Y6. Displacement of the Superconducting Critical Field by Pressure.*** N. L. MUENCH† AND H. E. RORSCHACH, JR., *The Rice Institute.*—An ice-bomb technique[1] (water is frozen in a constant-volume cell) has been used to obtain pressures of 1900 atmospheres to study the shift in the critical field of several superconductors. Data have been obtained at sufficiently low temperatures to determine the temperature dependence of $(\partial H_c/\partial P)_T$. For tin, one obtains $(\partial H_c/\partial P)_T = (\partial H_c/\partial P)_{T_c}[0.6+0.4(T/T_c)^2]$. This value is such that the

geometry[2] of the transition curve is preserved: $(H_0/T_c)_P = (H_0/T_c)_{P=0}$. $H_0$ is the value of the critical field $H_c$ at $T=0$. The shift of $H_0$ with pressure and the shift resulting from a change in isotopic mass can be used to calculate the dependence of $H_0$ on the lattice parameters and on the Debye $\theta_D$. The result indicates that $H_0$ is an order of magnitude more sensitive to fractional changes in lattice dimensions ($\theta_D$ constant) than to fractional changes in $\theta_D$ (lattice dimensions constant), i.e., $(\partial H_0/\partial \log V)_{\theta_D} \sim 10(\partial H_0/\partial \log \theta_D)_V$.

* Supported in part by the National Science Foundation.
† Magnolia Petroleum Company Fellow in Physics.
[1] B. Lazarev and L. Kan, J. Phys. (USSR) **14**, 439 (1944).
[2] E. Maxwell, Phys. Rev. **86**, 239 (1952).

**Y7. Surface Energies in Superconductors.** H. W. LEWIS, *Bell Telephone Laboratories.*—It is well known that the London phenomenological theory of superconductivity fails to account for the existence of a positive surface energy at the boundary between a normal and a superconducting region of a material. Modifications due to Landau and Ginsburg, and to Bardeen, make it possible to understand the positive surface energy as a specifically quantum-mechanical effect. However, these modifications change the London equations to a pair of coupled nonlinear differential equations, and only numerical solutions exist. A variational procedure for evaluating the surface energy within this framework will be discussed, and numerical results will be presented. These are relevant to the recent experiments of Schawlow. The possible existence of a gap in the electronic energy spectrum, and its effect on the predicted surface energy at low temperatures will be discussed, as well as the effect of a short electronic mean free path.

**Y8. A New Method for Measuring the Absolute Viscosity of Liquid Helium II.*** HENRY H. KOLM AND MELVIN A. HERLIN,† *M.I.T.*—A new type of static viscometer for use in liquid helium II was developed; its inner cylinder is suspended within a rigidly fixed, coaxial outer cylinder by a servomechanically controlled magnetic bearing of the type used by Beams and others[1] in vacuum ultracentrifuges. The inner cylinder is accelerated electromagnetically; the absolute viscosity of the medium is determined from the deceleration observed when it is permitted to coast freely. Bearing friction is negligible, and there is no inherent lower limit to the speed of this measurement. Reproducible viscosity values were obtained in gaseous helium, but $1/TS$-damping from thermomechanical flow induced by eddy current heating in the rotor was observed in liquid helium II. This effect was reduced considerably by elaborate precautions for isolating the apparatus from ground vibrations; further improvement would require more favorable location of the apparatus. At higher speeds, the anomalous behavior reported elsewhere[2] was again observed, which eliminates the attempted "mutual friction" explanation. The absolute viscosity increased discontinuously to a higher value as the speed increased.

* This work was supported in part by the Signal Corps; the Office of Scientific Research, Air Research and Development Command; and the Office of Naval Research.
† Now at Lincoln Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.
[1] Beams, Ross, and Dillon, Rev. Sci. Instr. **22**, 77 (1951).
[2] A. C. Hollis-Hallet, Proc. Roy. Soc. (London) **A210**, 404 (1952) and Proc. Cambridge Phil. Soc. **49**, 717 (1953).

**Y9. Ultrasonic Measurements in Magnetically-Cooled Liquid Helium.*** C. E. CHASE† AND MELVIN A. HERLIN,† *M.I.T.*—Measurements were made of the velocity and attenuation of ordinary (first) sound in liquid helium between 0.1°K and 1°K, at 12.1 Mc/sec. These temperatures were produced by adiabatic demagnetization of ferric ammonium alum from a starting temperature near 0.9°K, produced by a large oil diffusion pump. Since helium was admitted by an arrangement of concentric thin-walled stainless-steel cones (originated by Dr. J. Ashmead, Mond Laboratory), the demagnetization chamber could be isolated or placed in direct communication with the bath. Warmup times approximating one hour were obtained. The velocity remains essentially constant below 1°K at 240±5 m/sec. Although the inherent difficulty of a fixed path length makes it less accurate than the earlier 239±2 m/sec found above 0.85°K,[1] the value shows that no gross changes occur. The attenuation passes through two clearly resolved maxima slightly below 1°K, falls smoothly toward zero as absolute zero is approached. This agrees qualitatively with Khalatnikov's theory[2,3] which explains the anomalously high absorption of helium II in terms of two relaxation times.

* This work was supported in in part by the Signal Corps; the Office of Scientific Research, Air Research and Development Command; and the Office of Naval Research.
† Now at Lincoln Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.
[1] C. E. Chase, Proc. Roy. Soc. (London) **A220**, 116 (1953).
[2] I. M. Khalatnikov, J.E.T.P. (U.S.S.R.) **20**, 243 (1950).
[3] I. M. Khalatnikov, J.E.T.P. (U.S.S.R.) **23**, 8 (1952).

**Y10. The Amplitude Dependence of the Velocity of Second Sound.*** ALEXANDER J. DESSLER AND WILLIAM M. FAIRBANK, *Duke University.*—When second-order terms are considered in the theory of liquid helium II, Temperley[1] and Khalatnikov[2] have shown that the velocity of second sound is amplitude dependent and can be written in the form $C_2 = C_{20} + \tau_2 v_n$ where $C_{20}$ is the velocity of second sound at zero amplitude, $v_n$ is the velocity of the normal fluid and $\tau_2$ is a function of the temperature. Osborne[3] has qualitatively verified this equation by observing the shape of the shock wave in second sound pulses of large amplitude. We have measured $\tau_2$ as a function of temperature; $v_n$ was varied by superimposing a small marker pulse on top of a large carrier pulse of duration long compared with the length of the marker pulse. The time of flight of the marker pulse was measured as a function of the amplitude of the carrier pulse. Measurements of $\tau_2$ have been made from 2.1°K to 1.4°K. The experimental results will be compared with the theories.

* This project has been supported by contracts with the Office of Ordnance Research, U. S. Army.
[1] H. N. V. Temperley, Proc. Phys. Soc. (London) **A64**, 105 (1951).
[2] I. M. Khalatnikov, Doklady Acad. Nauk. U.S.S.R. **79**, 237 (1951).
[3] D. V. Osborne, Proc. Phys. Soc. (London) **A64**, 114 (1951).

**Y11. Kinetic Theory of Liquid Helium II: Heat Transfer.*** C. A. REYNOLDS, *University of Connecticut.*—A simple hydrodynamical treatment of two oppositely flowing, noninteracting fluids cannot be the proper method of handling heat transfer in helium II because of the microscopic interactions which must take place and which assure thermodynamic equilibrium or near thermodynamic equilibrium. Instead a phenomenological kinetic theory approach is used here. It is assumed that some of the atoms are in the condensed state and the others are "normally excited," following the ideas of the Bose-Einstein condensation. It is further assumed that the energy transfer may be broken up into two types—transfer of energy from atom to atom and transfer by motion of an atom with its associated energy. The former corresponds to a solid or phonon type of transfer and is not treated here. From a consideration of the latter type of transfer one can understand: the decrease in "conductivity" as the temperature is lowered; the existence of a maximum in the "conductivity"—temperature relationship; the shift in the maximum to higher temperatures as the slit width is reduced; the decrease in the heat "conductivity" as the slit width is reduced; and the "critical velocity."

* Supported in part by the Research Corporation, the National Science Foundation, and the Office of Naval Research.

**Y12. Heat Transfer in Fine Channels of Helium II.*** HAROLD FORSTAT AND CHARLES A. REYNOLDS, *University of Connecticut.*—An apparatus has been constructed for the measurement of heat transfer by liquid helium II in fine channels in packed rouge. It consists of a glass bulb containing a

heater and thermometer. Above this is a length of packed rouge; above this a glass-metal seal for the purpose of assuring thermal contact with the bath; and above this a glass viewing section. The bulb and rouge region are surrounded by a vacuum jacket. Helium is condensed into this system from a supply outside of the Dewar. The temperature below the rouge is measured by the thermometer in the bulb and the temperature above the rouge is measured by a thermometer placed inside of the metal seal. After heat is supplied one waits until the level in the viewing region comes to rest, assuring zero net mass transfer, and then notes the temperatures. The results will be compared with other data on heat transfer[1] and with theory.[2]

* Supported in part by the Research Corporation, the National Science Foundation, and the Office of Naval Research.
[1] W. H. Keesom *et al.*, Physica **13**, 153 (1947).
[2] F. London and P. R. Zilsel, Phys. Rev. **74**, 1148 (1948); C. A. Reynolds, preceding abstract, Bull. Am. Phys. Soc. **30**, No. 3, 69 (1955).

**Y13. The Slope of the λ Curve of Liquid Helium.*** K. R. Atkins, *University of Pennsylvania.*—Landau's theory of liquid helium has been developed to give an approximate value for the slope of the λ curve in terms of the quantities $(\rho/\Delta)(\partial\Delta/\partial p)$, $(\rho/\rho_0)(\partial\rho_0/\partial p)$, and $(\rho/\mu)(\partial\mu/\partial p)$. From the experimental data on the coefficient of expansion and the pressure variation of the velocities of first and second sound, the following numerical values are derived for these quantities: $(\rho/\Delta)(\partial\Delta/\partial p) = -0.57$, $(\rho/\rho_0)(\partial\rho_0/\partial p) = +0.26$, and $(\rho/\mu)(\partial\mu/\partial p) = -1.8$. The negative slope of the λ curve can then be explained and its magnitude predicted with an accuracy of about 15 percent.

* Work supported in part by the U. S. Atomic Energy Commission.

**Y14. PV Isotherms of $He^3$ Gas between 1.5 and 3.8°K.** William E. Keller,* *Los Alamos Scientific Laboratory.*—With the same apparatus[1] used recently to determine the equation of state of $He^4$, PV isotherms of 99.75 percent $He^3$ gas have been measured at 3.786°, 2.991°, 2.161°, 1.818°, and 1.515°K ("agreed" scale). Using the inverse volume virial expansion we obtain for the second virial coefficient, $B$, the respective values −65.4, −86.3, −117.9, −142.3, and −169.5 cc/mole. Only for the isotherms at the two highest temperatures is it necessary to include a quadratic term in the analytical expression in order to give a good fit to the experimental points. Discussions based on the properties of the isotherms will be presented on: the relation of the measured $B$'s to the recently calculated values[2]; the density of the saturated vapor as a function of temperature; and corrections to the "agreed" temperature scale below 4°K.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] W. E. Keller, Phys. Rev. **97**, 1 (1955).
[2] Kilpatrick, Keller, Hammel, Phys. Rev. **97**, 9 (1955).

**Y15. Theorem on the Many-Body Quantum Ground State.** P. J. Price, *I. B. M. Watson Laboratory.*—Let $\Psi_0(\mathbf{r}_1,\cdots\mathbf{r}_N)$ be the wave function of the ground state for a large number, $N$, of interacting particles (helium atoms, for example). We may construct a wave function for $N-1$ particles proportional to $\int\phi^*(\mathbf{r}_1)\Psi_0 d^3\mathbf{r}_1$. Then the condition that the energy expectation be not less than the energy of the ground state for $N-1$ particles gives an inequality for each function $\phi(\mathbf{r})$. If $\phi$ is chosen proportional to $\exp(i\mathbf{k}\cdot\mathbf{r})$, we find

$$\hbar^2k^2/2m+2w(\mathbf{k}) \gtrless h, \qquad (1)$$

where $h$ is the enthalpy per particle (partial enthalpy, for one species of several) and $w(\mathbf{k})$ is defined in terms of the reduced density matrices and may be interpreted (for zero external field) as the expectation of potential energy of a particle *when its momentum is* $\hbar\mathbf{k}$. Averaging (1) over the probabilities of different momenta gives the result that the total interaction potential energy cannot exceed $PV$. Consequences of these results will be discussed.

## Saturday Afternoon at 1:30

Continental Room

(R. W. Hayward presiding)

### *Radioactive Substances, II*

**YA1. Radiations from $Ce^{141}$ (33 hr).*** D. W. Martin, J. M. Cork, and S. B. Burson, *Argonne National Laboratory.*—The radiations from $Ce^{143}$ (33 hr) have been studied with the scintillation coincidence spectrometer and with magnetic photographic spectrographs. Enriched $Ce^{142}$ was irradiated with reactor neutrons. Gamma rays of 1.10±0.01, 0.861 ±0.005, 0.724±0.002, 0.668±0.002, 0.565±0.005, 0.493 ±0.002, 0.351±0.001, 0.294±0.001, 0.232±0.001, and 0.0574±0.0002 Mev are found to decay with the 33-hr period in the NaI(Tl) pulse-height distribution. Conversion lines are seen for all but the 1.10- and 0.57-Mev transitions. Gamma-gamma and beta-gamma coincidence data define the decay scheme with considerable certainty. The $Pr^{143}$ nucleus is shown to have excited states at 0.0574, 0.232 (or 0.493), 0.351, 0.724, 0.918, and 1.16 Mev. Qualitative observations of the beta-ray components were made by observing the pulse-height distributions from an anthracene crystal in coincidence with the principal gamma components. In addition to the known strong components at 1.38, 1.09, and 0.71 Mev, two distinct weak components at ~0.5 and ~0.3 Mev are observed, coincident with radiations from the 0.918- and 1.16-Mev levels respectively. The pulse distribution coincident with the 57-kev gamma ray is indistinguishable from the non-coincidence distribution above 1 Mev. Thus, the 1.38-Mev beta ray feeds the 58-kev level, and any ground-state beta transition is of low intensity.

* Work done under auspices of U. S. Atomic Energy Commission.

**YA2. The Excited States of $Ce^{140}$.*** C. H. Pruett, H. H. Bolotin, P. L. Roggenkamp, and R. G. Wilkinson, *Indiana University.*—Scintillation and magnetic beta ray spectrometry have been applied to the study of the more important levels of $Ce^{140}$. Coincidence experiments verify that successive levels are at 1.60, 2.09, 2.42, and 2.53 Mev above the ground state and correspond to gamma rays of energies 1.60, 0.815, 0.490, 0.438, and 0.328 Mev. The relative intensities of the gamma rays are found to be 2.50, 1.15, 1.25, 0.15, and 1.00, respectively. The energies and relative intensities of two high energy transitions have been determined by means of a scintillation pair spectrometer. Values of 2.50±0.05 and 3.00±0.20 Mev are obtained with corresponding intensities of one percent and 0.04 percent of the 1.60 Mev gamma ray. The beta-ray measurements substantiate the relative intensities and end-point energies of the beta-ray groups which have been reported by others. In addition, it has been possible to estimate the internal

conversion coefficients and $K/L$ ratios. The angular correlation of four cascade pairs of the above gamma rays has been studied. The results obtained, together with the beta ray and internal conversion data, are most consistent with the assignment 0+, 2+, 4+, 3+ for the ground state and first three excited states. The assignment 0+, 2+, 4+, 4+ cannot be definitely excluded.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**YA3. The Radioactive Decay of $Yb^{175}$.*** J. P. Mize, M. E. Bunker, and J. W. Starner, *Los Alamos Scientific Laboratory.*—The radiations from 4.2 day $Yb^{175}$ have been investigated and a decay scheme with spin and parity assignments proposed. Radioactive sources were obtained by irradiating normal ytterbium oxide with thermal neutrons. Examination of the beta spectrum with a magnetic lens spectrometer and a $\beta-\gamma$ coincidence scintillation spectrometer revealed the existence of three beta groups with end points 468, 355, and 72 kev and relative intensities $\sim(90{:}4{:}6)$, respectively. Scintillation spectrometer studies showed that gamma transitions of 113, 137, 145, 251, 283, and 396 kev occur. The decay scheme was established with the help of coincidence measurements. The multipolarities of the various gamma rays were determined from measured values of $K/L$ ratios, $L$ subshell conversion ratios, and $K$ conversion coefficients. The levels in $Lu^{175}$ excited by the decay of $Yb^{175}$ have the following energies: $113.6\pm0.2$ kev, $251.0\pm0.3$ kev, and $396.6\pm0.3$ kev. The possibility that the 113.6 kev and 251.0 kev levels are the first and second rotational levels, respectively, of $Lu^{175}$ predicted by the strong coupling approximation of the Bohr-Mottelson theory[1] will be discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selsk., Mat.-fys. Medd. **27**, No. 16 (1953).

**YA4. $\beta-\gamma$ Angular Anisotropy in $Re^{186}$.*** F. T. Porter, M. S. Freedman, T. B. Novey, and F. Wagner, Jr., *Argonne National Laboratory.*—The $\beta-\gamma$ directional correlation between the beta group leading to the first excited state in $Os^{186}$ and the ensuing 137-kev gamma ray has been measured as a function of $\beta$ energy from 200 to 900 kev. The anisotropy is consistent with the form $W(\theta)=1+A(E_\beta)\cos^2\theta$. The coefficient $A(E_\beta)$ increases with $\beta$ energy to a maximum $\cong0.16$ for energies near the end point. The integrated value of $A$ (200–900 kev) is $0.11\pm0.02$. The existence of this $\beta-\gamma$ anisotropy supports the nonallowed nonunique shape of the $\beta$ transition, $\Delta I=1$, yes, (see following abstract) and makes necessary a correction to the coincidence $\beta$ spectrum as observed in a magnetic spectrometer. For the Argonne double lens with 3 percent geometry for the gamma detector behind the source and with $\beta$ acceptance between cones of half angles 13° and 33°, the correction has the form[1] Observed Spectrum/$[1+0.4A(E_\beta)]\cong$True Spectrum.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Roland F. Herbst (private communication).

**YA5. Nonunique First Forbidden Beta Transitions in $Re^{186}$.*** M. S. Freedman, F. T. Porter, T. B. Novey, and F. Wagner, Jr., *Argonne National Laboratory.*—The main inner beta group ($E_0=936$ kev) in $Re^{186}$ has been observed, in the Argonne double-lens spectrometer, in coincidence with the 137-kev gamma, to deviate from the statistical shape. The effect on the spectrum due to the beta-gamma angular anisotropy (see preceding abstract) has been computed, and with an appropriate subtraction the ground state beta ($E_0=1073$ kev) has been likewise found to deviate from the statistical shape, both distributions consistent with $\Delta I=1$, yes transitions. An analysis of the spectral shapes and values for the fitting parameters will be presented.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

**YA6. Radiations from Platinum (197).*** V. R. Potnis,† C. E. Mandeville, and John S. Burlew,‡ *Bartol Research Foundation.*—The radiations of $Pt^{197}$ have been examined with coincident spectrometers of NaI−Tl and anthracene. Gamma rays have been detected at 77, 191, and 279 kev, the unconverted quantum radiations having relative intensities of 30, 3.9, and 1.0. Coincidence measurements revealed the presence of three beta spectra of maximum energies 670, 479, and 468 kev, terminating at levels in $Au^{197}$ at 77, 268, and 279 kev which are also excited[1,2] in the decay of $Hg^{197}$ and by coulomb excitation.[3] These beta spectra have intensities in order of decreasing end-point energy of 90.6, 8.4, and 1.0 percent. These estimates are based upon the observed gamma-ray intensities and upon previously determined conversion coefficients, experimental[1,2] and theoretical.[4] In the same order, values of log$ft$ are 6.4, 6.88, and 7.8.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Permanent address, Gwalior (M.B.), India.
‡ The Franklin Institute.
[1] Huber, Humbel, Schneider, de Shalit, and Zuenti, Helv. Phys. Acta **24**, 127 (1951).
[2] J. W. Mihelich and A. de Shalit, Phys. Rev. **91**, 78 (1953).
[3] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **93**, 906 (1954).
[4] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 79 (1951).

**YA7. Angular Correlation Measurements in $Hg^{197}$.*** Horace H. Coburn and Sherman Frankel, *University of Pennsylvania.*—The results of measurements of the various angular correlations in the 165 kev−134 kev cascade in $Hg^{197}$ will be discussed. The experimental values of $A_2$, corrected for geometry, are $HgNO_3(K-\gamma)$ 0.11; $Hg(K-\gamma)$ 0.11; $HgNO_3(L-\gamma)$ 0.12; $Hg(L-\gamma)$ 0.10; $HgS(L-\gamma)$ 0.09; $HgO(NH_2)NO_3(L-\gamma)$ 0.10; $HgO(L-\gamma)$ 0.08; $HgCo_3(L-\gamma)$ 0.11; $HgNO_3(M-\gamma)$ 0.11; $Hg(M-\gamma)$ 0.11; $HgNO_3(L+M-K)$ 0.19. Those data are accurate to $\pm0.02$ and indicate that the various correlations are insensitive to chemical environment. The theoretical $(K-\gamma)$ correlation is 0.221, so that there is appreciable wipeout. The "hard core" value is 0.044, so that the insensitivity cannot be due to complete saturation of the correlation by static external fields. The $HgNO_3(L+M-L)$ correlation was measured as a function of delay using a resolving time $t_0=0.5\tau$ where $\tau=8\times10^{-9}$ sec is the intermediate state half-life. Measurements at delays $\delta=-0.2\tau$, 0, $0.6\tau$, and $1.2\tau$ gave the (uncorrected) results 0.21, 0.19, 0.19, 0.18($\pm0.02$). Since the correlation does not fall off rapidly with delay, we conclude that the wipeout effects result from the excitation of the Hg atom following $K$, $L$, or $M$ conversion, that the resulting perturbations are short lived ($\approx<10^{-9}$ sec) and that the wipeout is not due to the fields of neighboring stoms.

* This work supported in part by the U. S. Office of Ordnance Research.

**YA8. The Excited States of $Hg^{199}$.*** Herbert H. Bolotin and Roger G. Wilkinson, *Indiana University.*—Scintillation coincidence counting techniques have been applied to the study of the cascade gamma rays which occur in the decay of the 45 min $Hg^{199}$ isomer. The $K$ conversion coefficient for the 0.159 Mev radiation is found to be $0.34\pm0.03$ in agreement with an $E2$ transition and with previous work.[1] $\alpha_K$ for the 0.368 Mev radiation is found to be $0.98\pm0.04$ and a value of $1.78\pm0.10$ is obtained for the total conversion coefficient of this transition. The measured $\alpha_K$ for the higher energy transition differs by a factor of four from the value expected for an $M4$ transition. Angular correlation measurements of the gamma rays yield a negative anisotropy of $-14.5\pm8$ percent instead of a positive 37 percent which would arise from a pure $2^1$–$2^4$ cascade. The conclusion is that the 0.368 Mev transition is a mixture of $M4$ and $E5$ radiation. A mixing ratio of $E5/M4$ of $30\pm20$ percent is suggested. A half-life of $42\pm1$ minutes was obtained for the decay.

* Supported by the joint program of the Office of Naval Research and and the U. S. Atomic Energy Commission.
[1] A complete list of authors appears in Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

**YA9. Photoproduction of $Pb^{207m}$.** W. L. BENDEL, M. E. TOMS, AND R. A. TOBIN, *Naval Research Laboratory.*—An 0.8-second activity has been observed by bombardment of lead with bremsstrahlung from the Naval Research Laboratory 22-Mev betatron. Data were obtained by cycling the apparatus. This activity is attributed to the reaction $Pb^{208}(\gamma,n)Pb^{207m}$. The pulse-height distribution observed with a scintillation counter is consistent with this assignment. The half-life was measured as 799±13 milliseconds. The apparent threshold is at approximately 10.2 Mev. The absence of any observable activity below 10.2 Mev indicates that the $Pb^{207}(\gamma,\gamma')Pb^{207m}$ reaction is negligible and also that this state is not measurably produced by neutron capture in $Pb^{206}$. The difference between this apparent threshold and the energy differential of 9.0 Mev (neutron binding energy plus energy of the metastable state) may be due to the spin change required (0 to 13/2) to reach this state.

**YA10. Metastable States in $Re^{180}$, $Ir^{191}$, $Au^{193}$, $Pb^{201}$, and $Pb^{203}$.*†** VERA KISTIAKOWSKY FISCHER, *University of California Radiation Laboratory and Columbia University.*—Activities produced in W, Ir, Pt, Au, and Tl targets by bombardment with 31.5-Mev protons were studied with scintillation and proportional counters. A grey-wedge pulse height analyzer was used for determination of gamma-ray energies. Excitation function studies were the basis for making assignments. Decay schemes will be proposed. The 7.4 sec $Au^{197m}$ and the 30 sec $Au^{195m}$ were also seen and their observed properties and excitation functions were used as a check on the interpretation of the other results.

| Assignment | Half-life | Gamma rays | Particles | Produced by |
|---|---|---|---|---|
| $Re^{180m}$ | 145±4 sec | 0.88, (0.51), 0.11 Mev, *K* x-rays | 1.1 Mev $\beta^+$ electrons | $W^{180}(p,3n)$ |
| $Ir^{191m}$ | 4.91±0.14 sec | 0.14 Mev, *K* x-rays | electrons | $Ir^{191}(p,p')$<br>$Ir^{191}(p,p2n)$<br>$Pt^{194}(p,3n)$<br>$Pt^{194}(p,2n)$ |
| $Au^{193m}$ | 3.88±0.25 sec | 0.26 Mev, *K* x-rays | electrons | $Tl^{203}(p,3n)$<br>$Tl^{203}(p,\pi)$<br>$Tl^{205}(p,3n)$ |
| $Pb^{201m}$ | 60.1 ±4.4 sec | 0.65 Mev, *K* x-rays | electrons | |
| $Pb^{203m}$ | 6.73±0.44 sec | 0.86 Mev, *K* x-rays | electrons | |

* This work was sponsored in part by the U. S. Atomic Energy Commission.
† Grateful acknowledgment is made of the Sarah Berliner Fellowship (1953–54) of the American Association of University Women which made this work possible.

**YA11. Internal Conversion Coefficients of $Tl^{203}$ (parent, $Hg^{203}$).** R. K. DOERNER AND A. H. WEBER,* *Saint Louis University.*—A method for internal conversion coefficient measurement is described utilizing an electron scintillation pulse-height spectrometer and consisting essentially in the measurement of the number of coincidences within the anthracene crystal between conversion electrons and the electrons from the continuous beta spectrum. This number divided by the number of noncoincident events yields the total conversion coefficient. For $Tl^{203}$ (parent, $Hg^{203}$) the conversion coefficient so measured is 0.11. When compared to 0.164 (by direct comparison of area under conversion and beta-spectrum curves) and 0.16 (from the ratio of *K* plus *L* x-rays to 280 kev gamma rays) this value, although low is sufficiently close to make the method feasible. The weighted mean value of the coefficients measured by the three indicated methods is $\alpha_K=0.147\pm0.002$ and $\alpha_L=0.045\pm0.001$; giving $K:L=3.29$. It is thus tentatively assumed that the 280 kev gamma ray is about 75 percent $E2$ plus 25 percent $M1$. According to the shell model the first excited state of $Tl^{203}$ is a $d_{3/2}$ state. The large amount of mixing should increase considerably the ratio $E2/M1$ compared to single particle estimates.

* Supported in initial phases of the work by the U. S. Atomic Energy Commission.

**YA12. Alpha-Gamma Directional Correlation in $Am^{241}$.*** T. B. NOVEY, *Argonne National Laboratory.*—Previous studies[1,2] of the alpha-60 Mev gamma directional correlation in liquid film sources of $Am^{241}$ have been continued. It is found that the attenuation due to electron quadrupole interaction in the liquid can be varied by the presence of ions of varying complexing strength and concentration. The results of a series of measurements involving ions of increasing complexing strength are as follows:

| Solutions | Anisotropy $[W(180°)-W(90°)]/W(90°)$ |
|---|---|
| 1*N* $HClO_4$ | −0.17±0.03 |
| 1*N* HCl | −0.19±0.04 |
| 6*N* HCl | −0.12±0.03 |
| 1*N* $H_2SO_4$ | −0.11±0.03 |
| 1*N* $HNO_3$ | −0.07±0.03 |
| 1*N* acetic acid | +0.03±0.03 |
| 1*N* $HClO_4$+1*N* citric acid | −0.02±0.04 |
| 1*N* $HClO_4$+1*N* versene | −0.04±0.03 |

These measurements were made with a resolving time, $2\tau$, of 0.15 microseconds. Measurements with shorter resolving times and varying delay times give an extrapolated anisotropy at zero delay of −0.22.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] T. B. Novey, Phys. Rev. **96**, 547 (1954).
[2] Raboy, Novey, and Krohn, Bull. Am. Phys. Soc. **30**, No. 1, 48 (1955), abstract S9.

## SATURDAY AFTERNOON AT 1:30

## Exhibit Hall I

## (W. K. H. PANOFSKY presiding)

### *Mesons, II*

**Z1. Pion Pair Production by Photons.*** R. M. FRIEDMAN,† K. M. CROWE, AND HANS MOTZ,† *Stanford University.*—In view of the anomalously large pair production of pions in nucleon-nucleon collisions and the considerable interest in the interpretation of pair-production processes, we report our attempts to observe pion pairs from 500- to 600-Mev bremsstrahlung on hydrogen. The method consists of looking for $\pi^-$ mesons produced by bremsstrahlung on liquid hydrogen; $\mu^-$ mesons are counted by delayed coincidences[1] resulting from the decay in flight of the $\pi^-$ meson. By subtracting the target-empty signal, we obtain a $H_3$ count which we hope to identify as $\pi^-$'s by observing: (1) proper deflection (~30°) in a magnetic field; (2) proper half-life for $\mu$ decay into electrons; and (3) disappearance below kinematic threshold. To date the signal we obtain does not fully meet these requirements so that our results are to be interpreted as upper limits. The ratio of $\pi^-$ to $\pi^+$ mesons at 55 Mev, 75° lab angle, with 590-Mev bremsstrahlung, is less than 3.7±0.4 percent. The results of a number of runs will be given and evidence concerning a lower limit will be presented.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the Engineering Laboratory, Oxford University.
[1] Crowe, Friedman, and Motz, Bull. Am. Phys. Soc. **29**, No. 8, 20 (1954), abstract L3.

**Z2. $\pi^-/\pi^+$ Ratios in Photoproduction.*** HANS MOTZ,† K. M. CROWE, AND R. M. FRIEDMAN, *Stanford University.*—We have observed variations of $-/+$ photopion production ratios for asymmetric nuclei which seem to be correlated with the difference in binding energy of the ground state of the residual nuclei for the negative and the positive production. For 280-Mev bremsstrahlung, a plot of the $-/+$ ratio *vs* $\Delta M = M_{Z+1,A} - M_{Z-1,A}$ gives a straight line for all elements measured, confirming the results of Littauer and Walker.[1] (In the event no stable isobar exists, the sum of the masses of the reaction products is used.) We have also measured $-/+$ ratios for Be, Li, and C, as well as Ca and Pb for various primary electron energies. At high energies (500 Mev) the $-/+$ ratio seems to tend toward the neutron-proton ratio within the experimental errors. Our results are consistent with the measured excitation functions (linear over a reasonably wide range) and the calculated threshold variations due to binding energy.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the Engineering Laboratory, Oxford University.
[1] R. M. Littauer and D. Walker, Phys. Rev. **86**, 838 (1952).

**Z3. $\pi^+$ Photoproduction in Carbon.*** K. M. CROWE, R. M. FRIEDMAN, AND HANS MOTZ,† *Stanford University.*—By varying the energy of the Stanford linear electron accelerator, we have measured the yields of positive photopions of $60\pm10$ Mev energy at 75° lab angle for 250- to 600-Mev bremsstrahlung. Our resolution and monitoring are checked with pions from hydrogen. The "efficiency" per proton, $\epsilon = \sigma_C/6\sigma_H$, is a slowly-varying function of the primary electron energy which approaches 0.95 at 500 Mev. A large fraction ($\sim\frac{1}{2}$) of the yield is obtained from photons of energy larger than 350 Mev. This corresponds to leaving the residual nucleus excitation energy of 100–300 Mev. Similar results are obtained for $40\pm10$-Mev $\pi^+$'s and $100\pm10$-Mev $\pi^+$'s. Various interpretations of this effect are considered and will be discussed qualitatively: (a) internal momentum distribution of the protons in the nucleus,[1] (b) variation of the production matrix element for free nucleons with angle and energy, (c) surface production and absorption effects, (d) coherent production, (e) density of final states in the residual nucleus for large excitation energies, and (f) form-factor effects.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the Engineering Laboratory, Oxford University.
[1] M. Lax and H. Feshbach, Phys. Rev. **81**, 189 (1951).

**Z4. Positive Pion Scattering by Hydrogen at 300 Mev.*** R. S. MARGULIES, *Brookhaven National Laboratory.*—The Brookhaven six-foot diffusion chamber has been used at the Cosmotron to study elastic scattering of $\pi^+$ mesons on hydrogen at 300 Mev. Assuming a total cross section of 75 mb,[1] the 115 events so far analyzed have c. m. angular distribution $d\sigma/d\Omega = 2.27+2.40\cos\theta+11.1\cos^2\theta$ mb/sterad. The Fermi-type phase shifts, assuming only $S$- and $P$-waves are found to be $\alpha_3 = -12°$, $\alpha_{31} = -10°$, $\alpha_{33} = 126°$. This experimental distribution strongly favors the theoretically predicted "track I" solution of de Hoffman, *et al.*[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. J. Lindenbaum and L. C. L. Yuan (private communication).
[2] de Hoffman, Metropolis, Alei, and Bethe, Phys. Rev. **95**, 1586 (1954).

**Z5. Scattering of 22-Mev Positive Pions on Protons.*** S. WHETSTONE AND D. STORK, *University of California, Berkeley.*—A beam of positive pions was passed through a $3\frac{1}{2}$-inch thickness of liquid hydrogen contained in a polyethylene-lined styrofoam target. The pions entered the hydrogen with a mean energy of $25.0\pm0.5$ Mev, and traversed the target parallel to the face of a stack of G. 5 nuclear emulsions, 6 inches long and $1\frac{1}{2}$ inches high, placed 1 inch from the beam edge. Tracks of scattered pions, identified at the end of their range in the emulsion by the characteristic decay-at-rest, can be followed back to the front surface of the stack, where measurements of the entrance angles can be made. It is possible to determine the scattering angle and energy for each event. We can therefore distinguish hydrogen events from elastic carbon scatters occurring in the 0.004-inch polyethylene liner. The pion beam was obtained by selecting pions produced at 0° in the reaction $p+p\rightarrow\pi^++d$, using quadrupole magnets to "strong-focus" the electrostatically-deflected 340-Mev proton beam of the Berkeley synchrocyclotron. Advantage was taken of the double-focusing properties of a wedge-shaped analyzing magnet. Fourteen scatters from hydrogen established to date yield a preliminary cross section of 3 mb for scattering in the interval 45°–135° in the laboratory.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

**Z6. Scattering of Negative Pions Near 15 Mev in Hydrogen.*** M. C. RINEHART, K. C. ROGERS, AND L. M. LEDERMAN, *Columbia University.*—The Nevis hydrogen-filled diffusion cloud chamber was employed in a search for low-energy negative pion scatterings of protons. The incident flux had a mean energy of 15 Mev, with a half-width of about 7 Mev. Significant contributions to the flux extended from 2.5 to 30 Mev. Twenty-six interactions were observed satisfying angular criteria based on length of recoil protons. The distribution of events in angle and energy was analyzed by the method of maximum likelihood. In this analysis, the Coulomb and $p$-wave contributions are treated as known and all of the data are used to determine the best $s$-wave phase shift, assumed to vary linearly over the energy interval. The result is $\alpha_3+2\alpha_1 = (0.25\pm0.05)\eta$ in radians. If this result is combined with $\alpha_1-\alpha_3$ obtained from the Panofsky effect *via* detailed balance, the quantity $\alpha_1+2\alpha_3$ is positive. If, however, the charge exchange scattering results of Tinlot and Roberts and Spry are used, $\alpha_1+2\alpha_3$ is negative, in agreement with $p_3$ mesic x-ray results.[1] The latter choice yields $\alpha_1 = +0.17\eta$, $\alpha_3 = -0.10\eta$ in agreement with Orear's suggestion.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Stearns, Stearns, DeBenedetti, and Leipuner, Phys. Rev. **97**, 240 (1955).

**Z7. Pion-Proton Total Cross Sections Near 4 Bev.*** K. C. BANDTEL, H. A. BOSTICK, B. J. MOYER, R. W. WALLACE, AND N. F. WIKNER, *University of California, Berkeley.*—Measurements are in progress of the total cross section subtended by protons and other nuclei for collision with pions of energies in the region of 4 Bev. When the Berkeley bevatron is operating at $10^{10}$ protons per pulse a negative pion beam of 4.4-Bev energy is available at 50 feet from the target with an intensity of about 0.4 pion per cm$^3$ per pulse. These conditions are typical of the energy-selected positive and negative pion beams in use. The muon contamination in these beams is at present estimated to be in the neighborhood of four percent, though further work on this point remains to be done. At the time of writing of this abstract, the $\pi^-$-proton cross section measured at 4.4 Bev is $30\pm5$ millibarns, and by the time of presentation of this work the limits of error should be reduced, and cross-section values for other nuclei are expected to be available. Measurements are made with a geometry which is calculated with respect to the Coulomb scattering of the mesons, and also with regard to the elastically scattered and secondary charged particles which might be detected in the final counter telescope.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**Z8. Pion-Proton Elastic-Scattering Cross Sections at 43 Mev and $37\frac{1}{2}°$.** S. W. BARNES, D. MILLER, J. RING, G. GIACOMELLI, R. SUMMERS, AND H. R. CHILDS, *University of Rochester.*—The differential $\pi$–$p$ scattering cross section of $43\pm3$ Mev pions has been measured at a laboratory scattering angle of $37\frac{1}{2}{}^{+10°}_{-\ 7°}$. The pions were scattered in a liquid hydro-

gen target, detected by a doubles telescope of two annular crystals and identified by the pulse heights yielded by the second annular crystal. The geometry of the detecting telescope was such that pions scattered from the walls of the hydrogen target were not counted. On the basis of the 200 pions of each sign scattered to date the $\pi^-$ and $\pi^+$ cross sections in the center-of-mass system are, respectively, $0.54\pm0.08$ mb/sterad and $0.27\pm0.04$ mb/sterad. The uncertainties given are mean deviations based on the counting statistics. Both the cross sections are approximately twice the value predicted by the recent Bethe-de Hoffman set of phase shifts.

**Z9.** (Abstract withdrawn.)

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## SATURDAY AFTERNOON AT 1:30

Caribar Room

(A. S. WIGHTMAN presiding)

### *Theoretical Physics, V: Field Theory*

**ZA1. Universal Singular Functions In Local Relativistic Quantum Field Theory.** A. S. WIGHTMAN AND D. HALL, *Princeton University.*—The vacuum expectation value of a product of $n$ Heisenberg operators is, from translation invariance, a function of the $n-1$ variables $x_1-x_2$, $x_2-x_3$, $\cdots$, $x_{n-1}-x_n$. If no negative-energy states exist, it can be extended to an analytic function of the variables $z_{12}=x_1-x_2-i\eta_1$, $z_{23}=x_2-x_3-i\eta_2$, $\cdots$, where $\eta_1$, $\eta_2\cdots$ vary in the interior of the forward-light cone. By virtue of Lorentz invariance the vacuum expectation value therefore becomes a sum of integrals with respect to invariant weight functions of certain universal singular functions which are the boundary values of analytic functions. For scalar fields, these latter functions can be written: $\Delta=\int d\mu(\Lambda)\exp -itr(\Lambda M)$, where $\Lambda$ is a homogeneous Lorentz transformation, $d\mu(\Lambda)$ is an invariant volume element on the group manifold, and $M^{\mu\nu}=\sum_{j=1}^{n-1} p_{j,j+1}{}^{\mu}z_{j,j+1}{}^{\nu}$. For $n=2$, one gets the well-known formula

$$\Delta=m^{-2}\Delta_m{}^{(+)}(z)=H_1{}^{(1)}[m(z_{12}{}^2)^{\frac{1}{2}}][8\pi im(z_{12}{}^2)^{\frac{1}{2}}]^{-1}.$$

For $n=3$ the analogous formula is

$$\Delta_{m_{12},m_{23},m_{13}}(z_{12},z_{23},z_{13})=[H_0{}^{(1)}((\alpha-(2\beta))^{\frac{1}{2}})-H_0{}^{(1)}((\alpha+(2\beta)^{\frac{1}{2}})^{\frac{1}{2}})](2\beta)^{-\frac{1}{2}}(8\pi i)^{-1},$$

where

$$\alpha=m_{12}{}^2z_{12}{}^2+m_{23}{}^2z_{23}{}^2+2(p_{12}\cdot p_{23})(z_{12}\cdot z_{23})$$

and

$$\beta=[(p_{12}\cdot p_{23})^2-m_{12}{}^2m_{23}{}^2]^{\frac{1}{2}}[(z_{12}\cdot z_{23})^2-z_{12}{}^2z_{23}{}^2]^{\frac{1}{2}}.$$

For spinor and tensor fields similar universal singular functions exist. They are obtained from the above by appropriate differentation and multiplication by $\gamma$ matrices.

**ZA2. Some Simple Results of Feynman Field Theory.** J. R. H. DEMPSTER, *Princeton University.*—The "sum over histories" in Feynman's method of quantization can be evaluated for any system with a quadratic Lagrangian, including noninteracting field theories.[1] However, the techniques for dealing with such quantities in field theory, involving differentiation and integration of functionals, are quite unfamiliar. In the simple example of a real scalar field, it is shown that these techniques present no especial difficulty and give consistent results, even though many of the integrals appear at first sight to be undefined. While the noncommutative operators of the usual quantum-field theory need never appear in this formalism (matrix elements of time-ordered operator products are given directly by Feynman sums), it is instructive to relate the two approaches by a direct calculation using the sum over histories. In this straightforward way an explicit form is obtained for these operators, in a representation in which the field strength is diagonal, and their commutation rules are derived.

[1] R. P. Feynman, Revs. Modern Phys. **20**, 367 (1948); Phys. Rev. **84**, 126 (1951).

**ZA3. A Generalization of Feynman's Integral Over-All-Paths Formulation of Quantum Mechanics.** Y. TAKANO AND J. L. ANDERSON, *University of Maryland.**—Schwinger's action principle[1] is applicable only to those problems where the kinetic energy is pure quadratic in the velocities. It is not at all evident how his formalism can be extended to deal with kinetic-energy terms of the form $\frac{1}{2}\dot{q}_iG^{ij}\dot{q}_j$ where $G^{ij}$ may depend explicitly on the coordinates. Feynman's formulation,[2] to which Schwinger's action principle can be shown to be equivalent, does appear to lend itself to a natural generalization for Lagrangians of the type considered. The arguments which led to this modification were based upon the results of an examination of the effect of changing variables in the original Feynman formulation. As was to be expected, it was found necessary to include the Jacobian of the transformation in the transformed integral. For a nonlinear transformation a pure-quadratic energy term goes over to the form considered above, and the Jacobian is $\sqrt{g}$ where $g$ is the determinant of $G^{ij}$. We propose therefore to include such a term in the general statement of Feynman's Postulate.

* Supported by Office of Naval Research.
[1] J. Schwinger, Phys. Rev. **82**, 914 (1951).
[2] R. P. Feynman, Revs. Modern Phys. **20**, 367 (1948).

**ZA4. Functional Integration and *S*-Matrix Theory.** JAMES L. ANDERSON, *University of Maryland.**—Ordering operators have been introduced into $S$-matrix theory[1] which allows one to write down the $T$-product of a functional of the field variables directly in terms of $N$- or normal-products of these variables. The rules for this expansion originally involved exponentials of functional differential operators and as such offered little hope

for practical application. In this paper it will be shown that, by introducing the concepts employed in functional integration, it is possible to convert these differential operators to integral form. When this is done, it is not surprising to find that the expressions obtained thereby are equivalent to Feynman's integral-over-all-paths formulation of quantum mechanics.[2] However, the expressions derived via $S$-matrix theory provide a simple rule for defining the normalization constant in Feynman's Theory. Also, these expressions allow one to express Feynman's integral in several alternate forms which might prove more convenient for actual calculation.

* Work supported by Office of Naval Research.
[1] J. L. Anderson, Phys. Rev. **94**, 703 (1954).
[2] R. P. Feynman, Revs. Modern Phys. **20**, 367 (1948).

**ZA5. Spectrum of a Bethe-Salpeter Equation.*** FREDERICK L. SCARF, *M.I.T.*—The spectrum of Wick's two-body equation[1] is investigated rigorously for arbitrary binding energy $\epsilon$. It is verified that for $\epsilon$ nonzero this singular equation has a complete point spectrum labeled by $n$, $l$, $m$, and $k$. The limit of zero $\epsilon$ is investigated, and it is shown that *all* eigenvalues tend to zero. This contradicts Wick's results which are shown to be based on an unreliable approximation. It is found that the set of eigenvalues $\lambda_n(k=0)$ give the best fit to the Balmer formula. The Bethe-Salpeter amplitudes on a space-like surface are also investigated. It is demonstrated that all amplitudes obey every known boundary condition at any $\epsilon$. It is also shown that the amplitudes are all well behaved and all are fairly good approximations to the hydrogen-atom wave functions in the N.R. region, but that those with $k=0$ give the best fit. While the solutions with $k=0$ seem to correspond to nonrelativistic ones, no rigorous criterion has been found to reject the "spurious" solutions.

* Assisted in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. C. Wick, Phys. Rev. **96**, 1124 (1954).

**ZA6. Space Inversion and Charge Conjugation for Fermion Fields.*** B. P. NIGAM AND L. L. FOLDY, *Case Institute of Technology*.—While the space-inversion transformation of a fermion field is fixed only to within an arbitrary phase factor, the space-inversion and charge-conjugation transformations commute only for a particular choice of this phase *modulo* $\pi$. Since situations exist (e.g. positronium) in which both transformations are diagonal, it would appear (paradoxically) that these would fix the phase. This point has been examined by constructing explicit representations of these transformations, with an arbitrary phase factor associated with each, in a form independent of an expansion of the fields in a set of orthonormal functions. The commutator has been found to be proportional to $\sin(\theta Q)$, where $\theta$ is the space-inversion phase and $Q$ the total-charge operator. Since charge conjugation can be diagonal only for states where $Q=0$, the commutator thus vanishes for such states independently of the value of $\theta$, thus resolving the apparent paradox. These special explicit representations of the transformations may be of value for other calculations.

* Supported by the National Science Foundation and the U. S. Atomic Energy Commission.

**ZA7. Re-examination of the Neutrino Theory of Light.** O. W. GREENBERG* AND A. S. WIGHTMAN, *Princeton University*.—Pryce's[1] formal argument that the requirements of relativistic invariance and Bose commutation rules are mutually inconsistent is not complete, in that he did not consider the most general bilinear combination of neutrino (and antineutrino) creation and annihilation operators. His argument has been extended to cover this case. The essential difference between the three-dimensional theory (which does not work) and the one-dimensional theory (which does) can be understood from the following schematic argument. The creation operator $c_1^*$ for the right circularly polarized photon of lowest momentum for a given direction contains the typical terms $a_{\frac{1}{2}}^{(+1)*}a_{\frac{1}{2}}^{(-1)}$, $b_{\frac{1}{2}}^{(+1)*}b_{\frac{1}{2}}^{(-1)}$, and $a_{\frac{1}{2}}^{(+1)*}b_{\frac{1}{2}}^{(+1)*}$, where $a_j^{(\pm 1)}$ is the annihilation operator for a right (left) circularly polarized neutrino of momentum $j$, and $b$ is the corresponding operator for an antineutrino. Note that in these operators angular momentum conservation requires adjoint for right circular polarization and no adjoint for left. This implies that the lowest two-photon state vanishes: $(c_1^*)^2\Phi_0 \propto c_1^* a_{\frac{1}{2}}^{(+1)*}b_{\frac{1}{2}}^{(+1)*}\Phi_0 \propto (a_{\frac{1}{2}}^{(+1)*}b_{\frac{1}{2}}^{(+1)*})^2\Phi_0 = 0$, where $\Phi_0$ is the vacuum state. This contradicts Bose statistics. In the one-dimensional case, there is no polarization, $c_1^*$ no longer commutes with $a_1^*b_1^*$, and the two-photon state doesn't vanish.

* National Science Foundation Predoctoral Fellow.
[1] M. H. L. Pryce, Proc. Roy. Soc. (London) **165A**, 247 (1938).

**ZA8. On Covariant Calculations of Polarization in Nucleon-Nucleon Scattering.** BURTON D. FRIED, *The Ramo-Wooldridge Corporation*.—As is well known, the polarization calculated from nonrelativistic, quantum mechanics using conventional, spin-dependent potentials, vanishes in lowest-order Born approximation (unless, as in the recent optical model calculations of polarization in nucleon-nucleus scattering, a complex potential is assumed). In higher orders it is possible to obtain a nonzero result if there are intermediate states whose energy coincides with that of the initial state, for these give rise to an imaginary component in the effective potential. The situation is quite similar in the relativistic case. In fact, if the interaction between nucleons arises from a quantized meson field, then it is possible to demonstrate that, to all orders of perturbation theory, contributions to polarization come entirely from "displaced poles" in the Feynman-Dyson-Wick formalism. Since only the imaginary component of the potential is needed, the polarization is considerably easier to compute, to a given order, than is the total cross section. (At an appropriate stage of the calculation, $(x-ia)^{-1}$ can be replaced by $\pi i\delta(x)$, which reduces by one the number of integrations over Feynman parameters.) Calculations of the $n$–$p$ and $p$–$p$ polarization are being carried out using $ps$–$ps$ meson theory.

**ZA9. Canonical Transformations of the Pseudo-vector Field.** M. EISNER, *Texas A. & M. College*.—A series of canonical transformations are employed to reduce the pseudo-vector Hamiltonian with pseudo-vector and tensor coupling to nucleons to a form which allows splitting of the field into longitudinal and transverse parts. Although the interaction term contains more complicated operators than in the original representation, this offers no difficulty in the strong coupling treatment of nuclear forces, self energy, and isobar energy problems. Agreement is obtained with the results of Rüdenberg[1] for strong coupling for pseudo-vector and tensor coupling alone. A simplification of the general interaction operator is discussed in terms of dichotomic variables implying extra degrees of freedom.

[1] K. Rüdenberg, Helv. Phys. Acta **24**, 89 (1951).

**ZA10. Approximately Relativistic Equations.** M. KLERER* AND R. D. HATCHER, *New York University*.—A modified Breit equation for two particles, with anomalous moments, has been examined. The Foldy-Wouthuysen method is used for reduction to a Pauli form. A previously used procedure of replacing the spin operator $\sigma$ by $\mu\sigma$, where $\mu$ is the actual magnetic moment in units of Bohr (or nuclear) magnetons, is shown to be inconsistent with the modified equation. The limits of applicability of the previous procedure, in transforming to the actual magnetic moment, is discussed as a function of the mass. This phenomenological treatment yields good results when applied to the fine structure and hyperfine structure of hydrogen. Effects due to the finite mass and magnetic moment of the proton are directly reduced from the two-body equation.

An examination is made of certain terms usually neglected in applications of the normal Breit equation. Difficulties arising from application of an approximately relativistic one body equation to hyperfine structure are discussed and an alternate method is proposed. The relationship of the Foldy-Wouthuysen method to that of "large components" is also examined.

* Now at The City College, New York City.

**ZA11. On the Lee Model.** KATSUMI TANAKA, *Argonne National Laboratory.**—Lee[1] has treated some simple one-particle problems of interacting fields that are both renormalizable and solvable in order to obtain some deeper insight as to the nature of the renormalization procedure without the use of perturbation method. One of the peculiar results of Lee is that the renormalized coupling constant cannot be realized by any limiting process if $g$, the unrenormalized constant, is restricted to be on the real axis. We have treated the two-particle state within Lee's formalism and obtained an integral equation that determines the binding energy of the two particles, if there are bound states. It is expressed in terms of the renormalized mass and coupling constant which were obtained from the one-particle state. It is shown that when the upper limit in momentum space goes to infinity, the integral equation for the binding energy involves divergent integrals. In other words, Lee's formalism for two particles is not free from divergent integrals. The reasons for this are given.

* Work done under the auspices of U. S. Atomic Energy Commission.
[1] T. D. Lee, Phys. Rev. **95**, 1329 (1954).

**ZA12. On Quantum Electrodynamics and the Mass Operator.** W. WESSEL, *U. S. Air Force Institute of Technology.*—In a theory of the electron proposed by the author,[1] quantization of the electromagnetic field is accomplished by the choice of infinite matrices in place of Dirac's. The mass term is then of the form[2] $m=m(I,K)(I^2+K^2)^{\frac{1}{2}}$, where $I$ and $K$ are the invariants of the momentum tensor and $m(I,K)=m_0\sinh(\Gamma K)$ with $\Gamma=(3/2)(\hbar c/e^2)=205.5566\pm0.0024$. In a $K$-representation the infinite matrices are represented by difference operators,[3] which makes the square root very unwieldy. It has been found, that the nonlinear difference equation $(1/2i)[\theta(K+i)-\theta(K-i)]=K/\theta(K)$, which may be considered as the quantum analog of $\partial(I^2+K^2)^{\frac{1}{2}}/\partial K=K/(I^2+K^2)^{\frac{1}{2}}$, has a simple solution $\theta(K)$. With its substitution for $(I^2+K^2)^{\frac{1}{2}}$ the rest mass problem may be reduced to a difference equation with a periodic coefficient, that admits a closed solution for spin $\frac{1}{2}$, if $\Gamma$ can be approximated by a rational multiple of $\pi$. With $\Gamma=64\pi+10\pi/7=205.54992\cdots$ one finds one mass eigenvalue $m/m_0$ at $-1$ and two complex conjugate ones close to $+1$ on the unit circle. The complex ones may be interpreted by the fact that quantization of the $\psi$-field has not yet been accomplished.

[1] W. Wessel and S. J. Czyzak, Phys. Rev. **91**, 986 (1953).
[2] W. Wessel, Phys. Rev. **83**, 1031 (1951).
[3] W. Wessel, Z. Naturforsch. **7a**, 583 (1952).

**ZA13. Transformation Groups in Configuration Space.*** IRWIN GOLDBERG AND ALLEN JANIS, *Syracuse University.*—The canonical type transformations in the Lagrangian formalism[1] have been studied to determine whether the analogue of the Dirac bracket transformations[2] can be identified. The group theoretical commutators are used to construct the group of transformations in configuration space which has a normal subgroup the transformations generated by the constraints. The factor group of this subgroup has a one to one correspondence with the permissible generators. The observables of the quantized theory are to be identified with the permissible generators.

* Supported by Office of Naval Research.
[1] P. G. Bergmann and R. Schiller, Phys. Rev. **89**, 4 (1953).
[2] P. G. Bergmann and I. Goldberg, Phys. Rev. (to be published).

**ZA14. Peierls' Introduction of Canonical Transformations into the Lagrangian Formalism.*** PETER G. BERGMANN, *Syracuse University.*—It will be shown that an approach due to Peierls[1] and one due to Bergmann and Schiller,[2] to define canonical transformations in the Lagrangian formalism, are equivalent, at least in the realm of theories considered by Peierls, in which the matrix of coefficients of the terms quadratic in the velocities is regular. The extension of the Lagrangian formalism to theories with singular matrix will be discussed in a separate abstract by Goldberg and Janis. Peierls has suggested quantization on the basis of so-called $c$-number variations. From the present discussion a different possibility emerges: To construct the group of permissible and interesting transformations in the $c$-number theory, to retain only those observables that generate these transformations, to determine the commutators group-theoretically, and for consistency to test that the proposed set of infinitesimal transformations forms indeed a group. Work designed to test the efficacy of this approach is now in progress.

* Supported by Office of Naval Research.
[1] Proc. Roy. Soc. (London) **A214**, 143 (1952).
[2] P. G. Bergmann and R. Schiller, Phys. Rev. **89**, 4 (1953).

**ZA15. Expansion of Two-Dimensional Wave Fields in Powers of $1/\rho$.*** HARVEY EINBINDER, *Technical Research Group.*—If solutions of the two-dimensional wave equation exist of the form $\frac{e^{ik\rho}}{e^{\frac{1}{2}}}\sum_{n=0}^{\infty}\partial_n(\theta)\rho^{-n}$, a recurrence relation connecting successive coefficients is obtained formally by substituting this series into the wave equation, namely:

$$2ik(n+1)\partial_{n+1}=(n+\tfrac{1}{2})^2\partial_n+\frac{\partial^2\partial_n}{\partial\theta^2}.$$

This expansion is then derived by steepest descents from an integral representation of the solution from which it is shown that the series is asymptotic and cannot converge for more than a single value of $\theta$ regardless of the aperture field. This is in contrast to three-dimensional wave fields where such expansions are uniformally and absolutely convergent. However, the total field in two dimensions is uniquely determined by the values of the far field by means of an integral representation. These results are illustrated by the cylindrical waves $H_\nu^{(1)}(ke)$.

* This research was supported by the Air Force Cambridge Research Center.

# SUPPLEMENTARY PROGRAMME

**SP1. Production of Electrostatic Charges by Rotation of a Permanent Magnet.** OLEG YADOFF.*—A slender cylindrical magnetized rod, long in relation to its diameter, which rotates rapidly about its longitudinal axis, engenders thereby electrostatic charges on its surface and produces in the surrounding medium a strong electrostatic field. Conditions under which this occurs have been determined experimentally. The direction of rotation determines the sign of the electrostatic field. If two rods rotate in opposite directions, the fields obtained have opposing directions: (+) and (−). The two rods then undergo mutual attraction, under Coulomb's law, which provides also for the converse, namely that like fields are mutually repellent. The complexity of the electromagnetic processes involved in the occurrences both within and around the rod is such that no definite conclusion has as yet been possible. Nevertheless, these observations tend to support the hypothesis, put forward by the author some time ago, that in general so-called electrostatic fields should be considered as but one aspect of the basic electromagnetic phenomenon.

* To be called for at the end of Session KA if the Chairman rules that time permits.

**SP2. An Energy Control for External Cyclotron Beams.*** G. SCHRANK, *Princeton University*.[1]—In order to eliminate the uncertainty in energy of the external 18-Mev proton beam from Princeton's *FM* cyclotron without the manufacture of large steering magnets, a device was constructed which stabilizes the mean energy of the beam to better than 0.1 percent. The device looks at the end of the range of a sample of protons which are elastically scattered from a very thin intercepting foil. This group of scattered protons is allowed to spend most of its range in aluminum and then enters and stops in an argon filled parallel-plate ionization chamber. By a double electrode arrangement which collects the ions produced at the end of the range, the mean energy of these protons is determined, and by feeding the difference signal from these two collectors back into the cyclotron magnet-current control, the energy is automatically stabilized. Better than 0.1 percent control can be achieved with as few as 500 protons entering the ion chamber per second.

* Work supported by the Atomic Energy Commission and The Higgins Fund.

[1] To be called for at the end of Session T if the Chairman rules that time permits.

**SP3. Physical Significance of the Three Quantum Numbers.** GERTRUDE T. SCHWARZMANN.*—The stationary orbits described by the satellite electrons are eccentric circular, earthial orbits. Upon the motion therein is imposed the quantum condition $2r_n pi = 2n \cdot \lambda$ as prerequisite to the fulfillment of the particular law of conservation of orbital angular momentum imposed upon the interaction between electrons and photons; this law explains the origin of the always positive, multivalued spin-quantum number: "The fraction of the spin component transformed in the transition orbit into a second revolutional component increases if emitting electron and emitted photon revolve in opposite senses; it decreases if they revolve in the same sense, by the magnitude of the orbital angular momentum of the photon," which revolves about the nucleus in a circular orbit, its radius the perihelion value $k \cdot r_n/2n$ ($k = 1, 2, \cdots n$) of the radius vector of the electron in its particular $n$th orbit. Computation shows that the electrons describing transition orbits with perihelion value $k \cdot r_n/2n$ emit the corresponding lines of the $n$th series as $(k-1)$st harmonics. When energy from without is added to hydrogen atoms in the normal state, the emission of the Lyman and Balmer series tells that the emitting electrons have described the transition orbits leading to the first and second orbit, respectively.

* To be called for at the end of Session VA if the Chairman rules that time permits.

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DeStaebler, Jr., H., H. S. Bridge, B. Rossi, and B. V. Sreekantan—P7
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Doerner, R. K. and A. H. Weber—YA11
Drell, S. D.—D11
Driscoll, Raymond L.—KA8
Eguchi, Tetsuo—D14
Einbinder, Harvey—ZA15
Eisner, M.—ZA9
Ellis, J. A., M. B. Gottlieb, and L. H. Meredith—A10
Ellis, Robert A.—A11
El-Sum, Hussein M. A. and Albert V. Baez—FA11
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Farmer, Donald J.—V7
Ferrell, R. A.—R10
Feynman, R. P.—U3
Finkelstein, David—RA13
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Forstat, Harold and Charles A. Reynolds—Y12
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Friedman, M. H. and T. D. Lee—D2
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Gartenhaus, S.—D12
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Goldberg, Irwin and Allen Janis—ZA13
Goldberg, W. I.—CA8
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Gora, E. K.—XA2
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Greenberg, Howard and Sidney Borowitz—HA1
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Griem, H. and S. F. Singer—A5
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Salter, L.—UA1
Salzman, G.—D10
Sands, M., M. Bloch, J. G. Teasdale, and R. L. Walker—S12
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Schwarzmann, Gertrude T.—VA15, SP3
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Steffen, R. M.—V8
Steinberg, M. S.—X9
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Sternheimer, R. M.—D5
Stiller, B., M. M. Shapiro, and N. Seeman—P6
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Stork, D. and S. Whetstone—S4
Strandberg, M. W. P.—XA9

Sunyar, A. W.—H3
Swan, P. R. and M. W. P. Strandberg—XA8
Swann, W. F. G.—RA15
Takano, Y. and J. L. Anderson—ZA3
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Uhlir, Jr., A.—C11
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Visscher, William M. and Richard A. Ferrell—RA8
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